REFERENCE 29

J. CAROTHERS, "HAZARDS SUMMARY REPORT FOR THE LRL CRITICAL FACILITY," LAWRENCE RADIATION LABORATORY REPORT UCRL-6220 (MARCH 1960).

UCRL 6220

UNIVERSITY OF CALIFORNIA

Ernest O. Lawrence

Radiation Laboratory

HAZARDS SUMMARY REPORT FOR THE LRL CRITICAL FACILITY

LIVERMORE SITE

UCRL-6220
Criticality
Studies, UC-46,
TID-4500 (16th Ed.)

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Livermore, California

Contract No. W-7405-eng-48

HAZARDS SUMMARY REPORT FOR THE LRL CRITICAL FACILITY

James Carothers

March 3, 1960

Printed in USA. Price $2.50. Available from the
Office of Technical Services
U. S. Department of Commerce
Washington 25, D.C.

CONTENTS

HAZARDS SUMMARY REPORT FOR THE LRL CRITICAL FACILITY

James Carothers

Lawrence Radiation Laboratory, University of California
Livermore, California

ABSTRACT

The Lawrence Radiation Laboratory has, since 1952, operated a critical facility at the Livermore Site. A large number of critical and sub-critical measurements on all types of systems of fissionable material have been made during this time. The two original assembly vaults are still in continuous operation in support of the weapons and propulsion reactor programs of the laboratory. An additional critical assembly cell has recently been completed to provide more facilities for critical assembly measurements. This cell is unusual in that it is in a containment building which can be sealed to prevent release of any radioactive or toxic material to the atmosphere.

Typical moderated and unmoderated core assemblies are explained and analyzed to demonstrate the procedures at the LRL critical facility. Credible accidents are shown to be less than 10^{18} fissions for these systems. The safety features of both the old and new cells are shown to have an adequate margin to contain all consequences of such accidents, including prompt and delayed radiation, fission products and any dispersed core material.

I. INTRODUCTION

The Lawrence Radiation Laboratory has, at its Livermore Site, conducted a program concerned with the design and test of various types of fission devices since 1952. Fundamental to such design is an experimental program to furnish data for the theoretical and calculational work at the laboratory. From the time the Livermore Site was established there has been an active program of critical and sub-critical mass measurements, involving all types and forms of fissionable materials. Assemblies involving metal systems, solutions and various metal-moderator cores have been made and well over a thousand approaches to critical have been performed.

The first facility for sub-critical measurements was a setup in a men's shower room in one of the original World War II barracks buildings on the site. During the remainder of 1952 and 1953 other assemblies to support the weapons programs were made in a temporary shielded vault, since removed, and in an isolated area with a remote (1000 feet from the assembly) control room. In the summer of 1954 work was completed on a 30' x 20' and a 15' x 20' vault in Building 110. During the following five years a large number of different types of critical and sub-critical assemblies were made to support the weapons program and the Pluto program in these vaults.

A new facility, described in detail in this report, was completed in September, 1959. Operational experience in the old vaults suggested several new features which would increase the safety and utility of the area and these have been incorporated in the design. These include a containment shell for the vault to prevent the spread of any possible radioactive contamination; complete, massive concrete shielding including the roof; air conditioning to control temperature induced reactivity changes and provision for decontamination of all walls and floors. This facility makes possible the conduct of all of the types of assemblies which have been made in the past and will allow future work to be done at core powers of from one to ten kilowatts should this be necessary.

The purposes of this report are:

1) To provide a document which will outline the operating procedures for critical assembly work at LRL and which will describe the existing facility.

2) To provide a document for reference in any future analyses of the hazards associated with various experimental programs.

3) To demonstrate that past procedures have been consistent with the highest of safety standards and that future operations will be conducted in a manner which will lead to the absolute minimum of danger both to the public and to laboratory personnel.

A critical facility is, of course, different from a reactor operating at power for considerable periods of time. In particular there is never an appreciable inventory of fission products in the fuel. Measures are, in fact, taken in the design of experiments to prevent such buildup because of the necessity of manual operations on the fuel. On the other hand, a reactor represents an essentially unchanging operation where the core geometry and control system are the same from day to day, while a critical facility involves a wide variety of experiments which by their nature mean different geometries, fuel types, control systems, assembly methods and operating characteristics. The hazard of a criticality accident is considerably greater in a critical facility than with a reactor, but it is difficult to imagine a situation where a critical accident in a critical facility can endanger anyone other than operating personnel. This is in marked contrast to the potentially catastrophic consequences of a major reactor accident.

In the report which follows, the general form of a hazards report for a reactor will be followed, but in some areas such as description of procedures and protective devices, and analysis of the maximum credible accident, only typical systems can be discussed since programs are continually changing. The activities of the Lawrence Radiation Laboratory are such that each situation involving fissionable material is likely to be unique and therefore must be considered separately. Consequently, exceptions to any set of general principles are often necessary in specific cases.

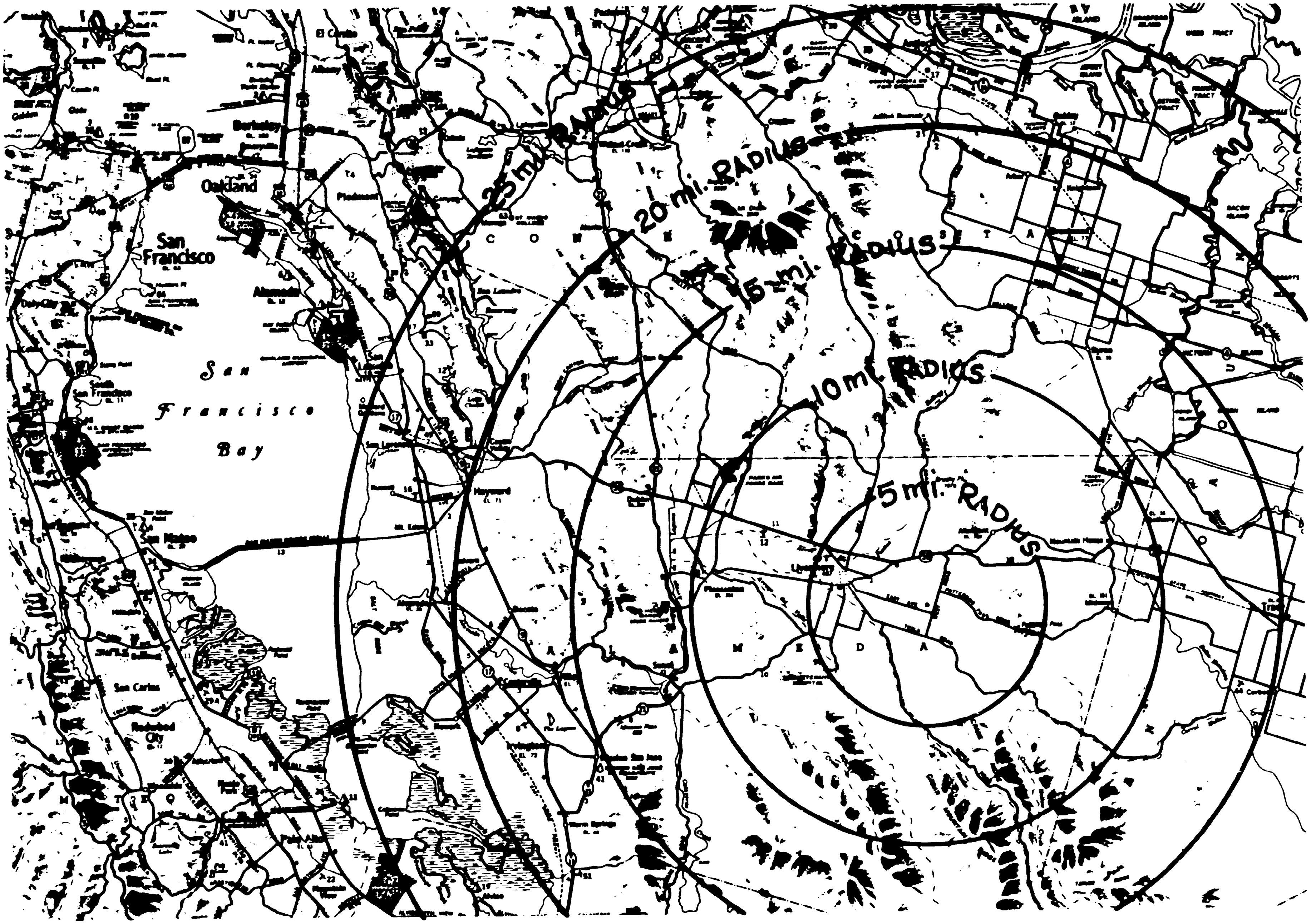
II. SITE DESCRIPTION

2.1. LOCATION AND GENERAL FEATURES

The Lawrence Radiation Laboratory, Livermore Site, is located approximately 35 miles east of Oakland at the eastern end of the Livermore Valley. Location of the laboratory, with respect to the San Francisco - Oakland area is shown in Figure 2-1. The laboratory site consists of 640 acres located on the northwest corner of the intersection of East Avenue and Greenville Road. The location of the site with respect to the local area is shown in Figure 2-2. The site was formerly a naval air base used for primary flight training during World War II. Many of the original buildings are still in use, but they have been supplemented by a large number of permanent buildings constructed since 1952. An aerial photograph of the site is shown in Figure 2-3. The relation of the laboratory site to the town of Livermore is shown in Figure 2-4, which is another aerial photograph. A map of the site showing distances from the critical facilities to the other areas is given in Figure 2-5.

The Livermore Valley is roughly elliptical in shape. The long axis of the valley runs east and west and is about 13 miles long. At its eastern end the valley is six to seven miles wide; in the center and western portion it is three to four miles wide. The total area of the valley is about 58 square miles. The valley is completely surrounded by hills ranging from 1000 to 2000 feet above sea level, except at the northwest corner. Here the Livermore Valley connects with the Amador Valley, a long narrow valley which extends north-northwest to the towns of Danville and Walnut Creek. These communities are approximately twenty and twenty-five miles from the laboratory site. In the southwest corner of the Livermore Valley there is a small opening through the hills which provides the only water exit from the valley.

The floor of the valley is relatively flat and it contains only a few small hills. It slopes from about 600 feet MSL at the eastern end to about 400 feet MSL at the western end. U. S. Highway 50 enters the valley at the western end and travels the length of the valley, leaving the eastern end through Altamont Pass. This highway passes about two miles north of the critical facility at its closest approach. Two rail-



MUL-8804

FIGURE 2-1 SAN FRANCISCO AREA

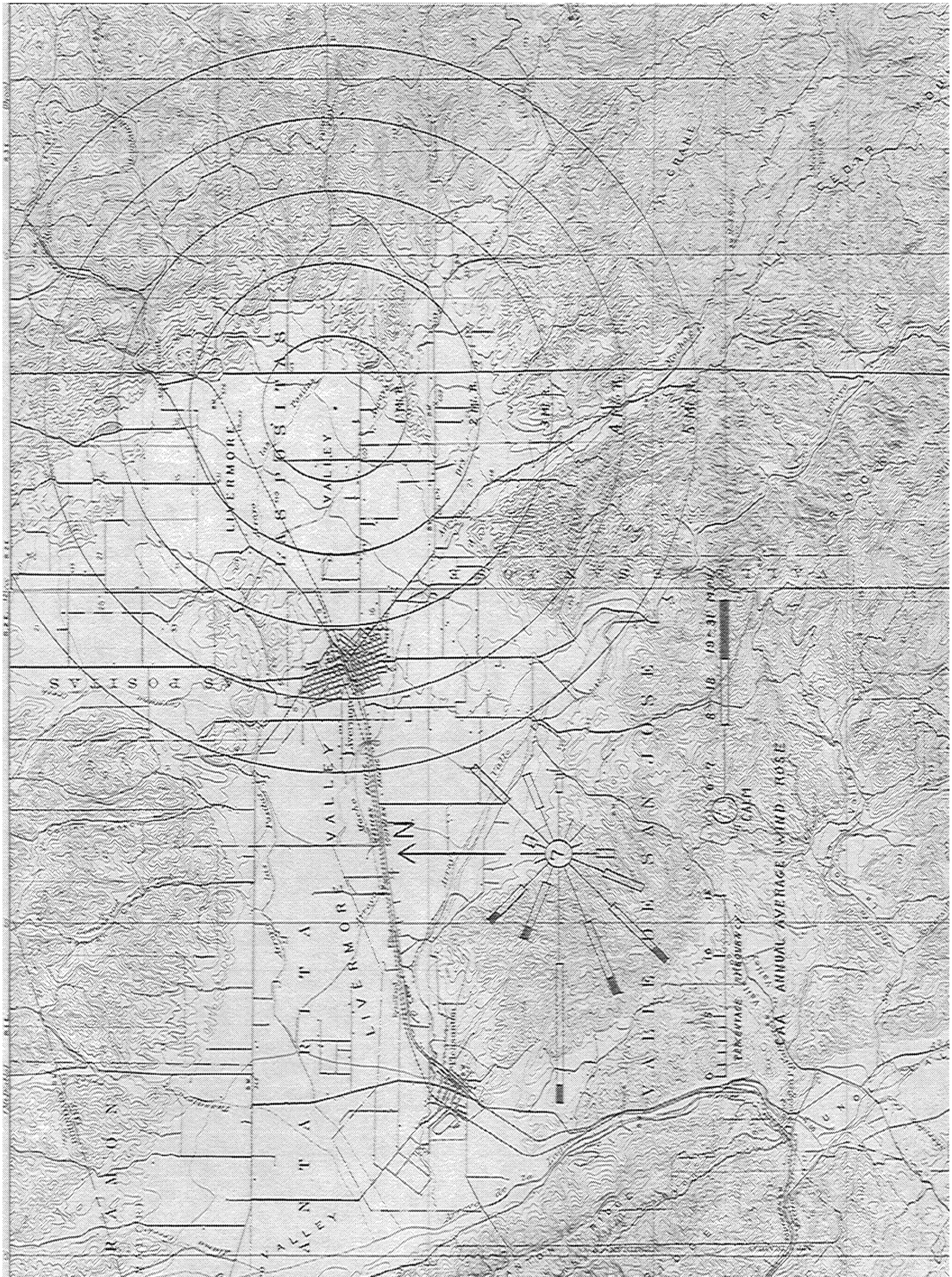
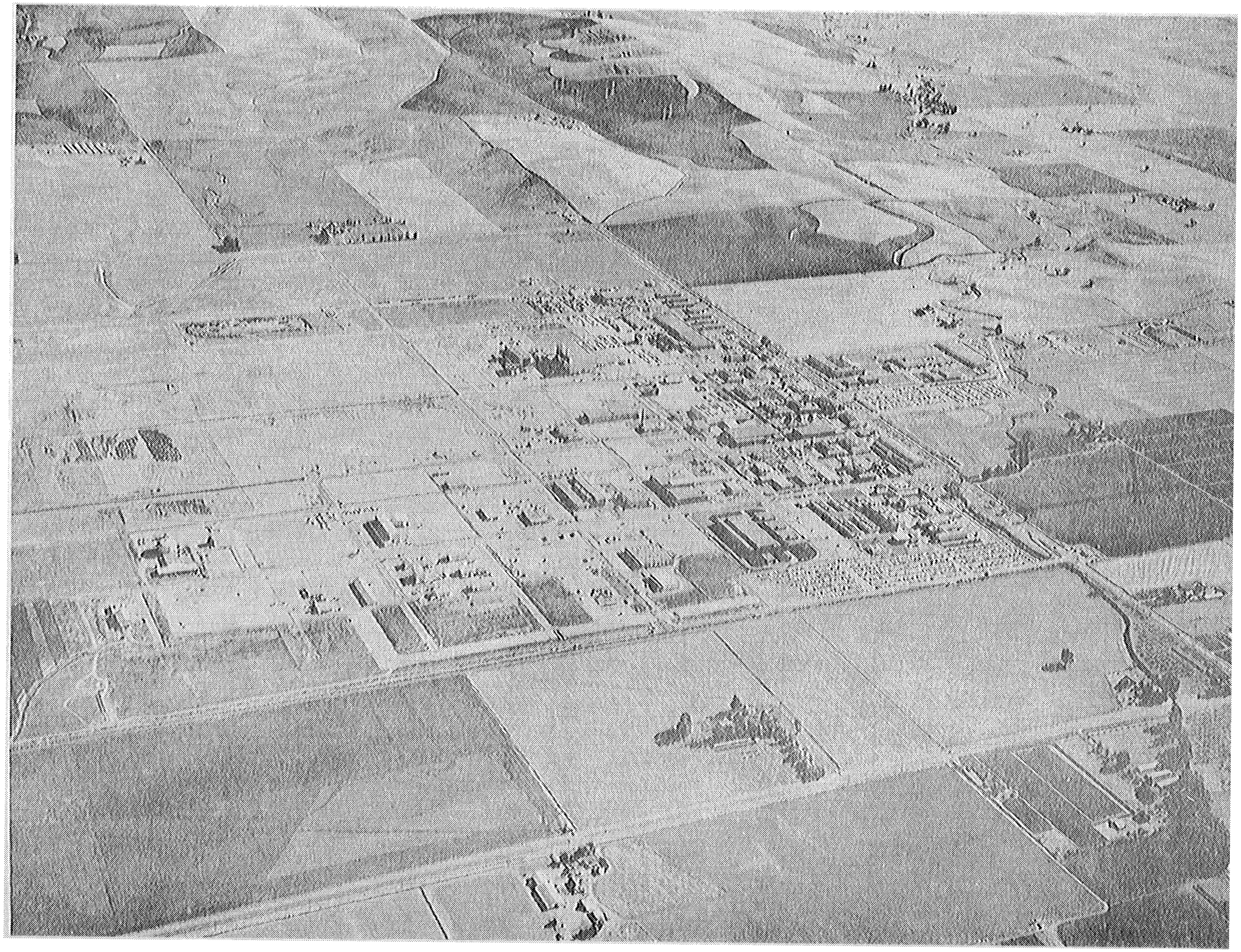

LIVERMORE
VALLEY
ANNUAL AVERAGE WIND ROSE
PERCENTAGE FREQUENCY
CALM
POSITAS

FIGURE 2-2



SN-18498

Fig. 2-3. Aerial View of the Lawrence Radiation Laboratory, Livermore Site

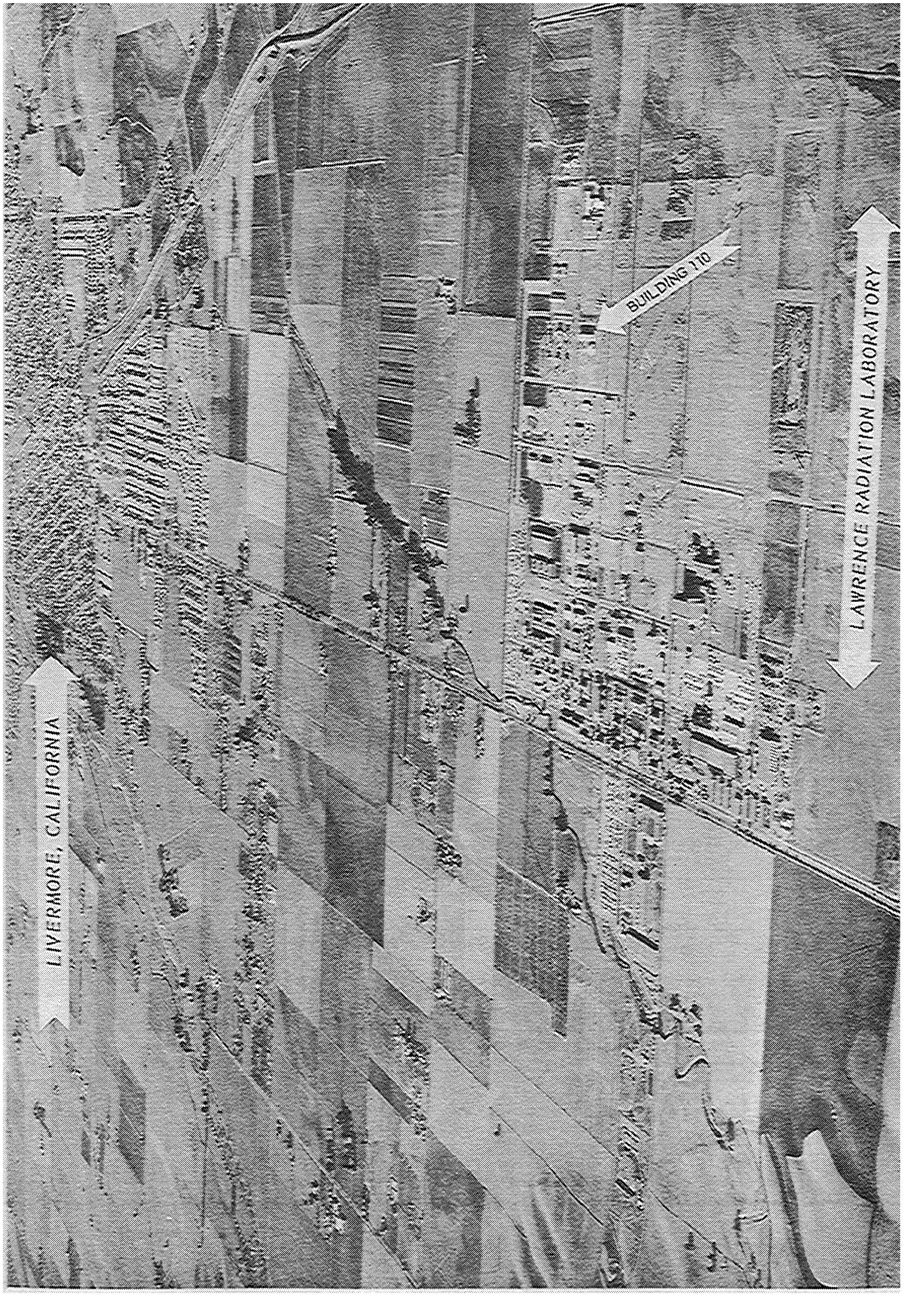


FIGURE 2-4. AERIAL PHOTO

SN-23654

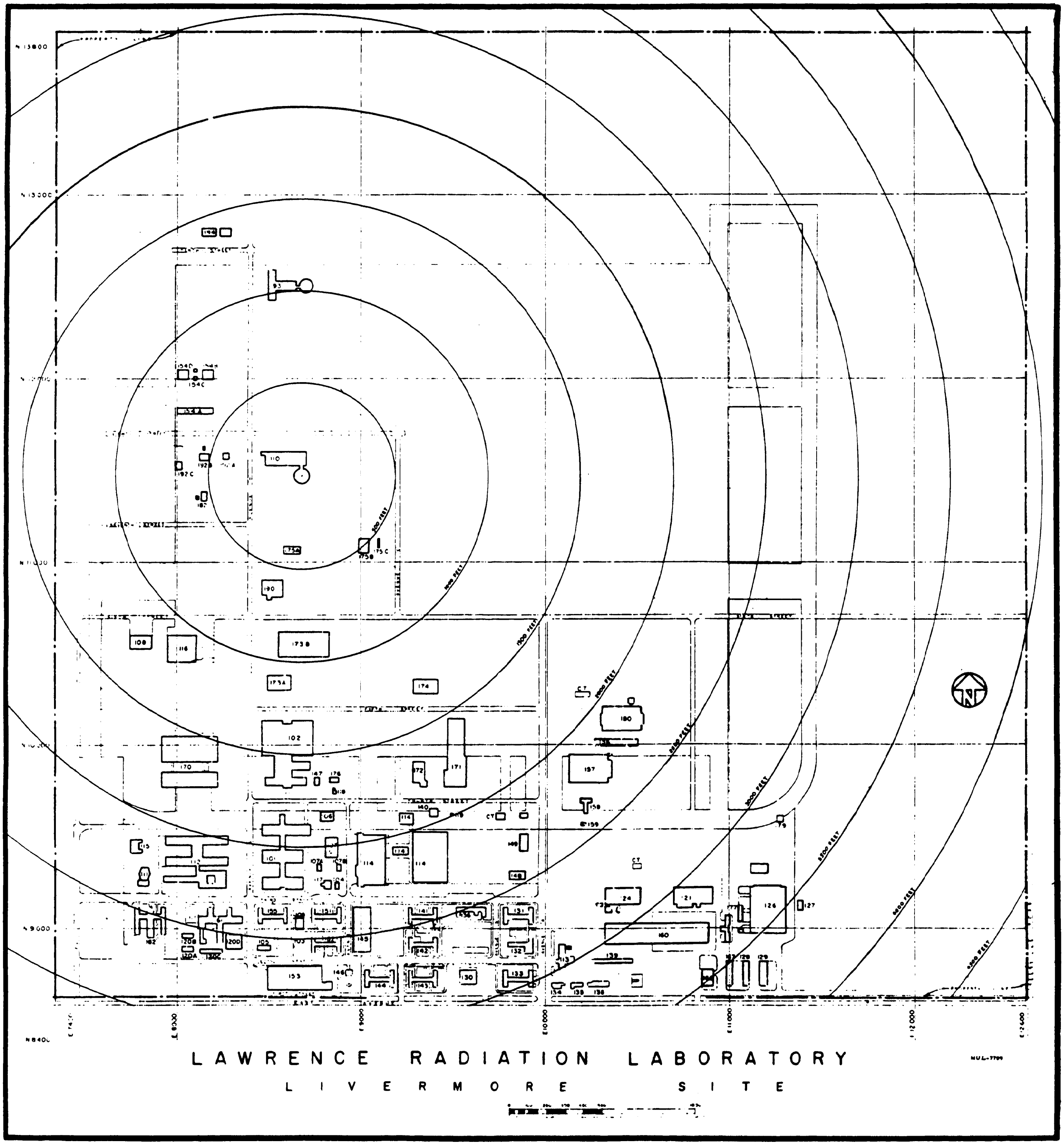


FIGURE 2-5

roads also pass near the site. The Western Pacific and Southern Pacific tracks come through Altamont Pass and travel west to the town of Livermore. At the closest approach the Western Pacific tracks are about one mile and the Southern Pacific tracks about one and one-half miles from the facility.

Agriculture is the major activity in the valley. The chief products are grains, dairy products and cattle, grapes and alfalfa. Some irrigation of crops is carried on during the summer, with about 3000 acres under development. Several large gravel plants are located between Livermore and Pleasanton. West Coast Industries, which produces fuses and the Livermore branch of the Sandia Laboratories are the main industrial concerns in the valley. The city of San Francisco has several large wells in the southwest corner of the valley. These serve as a supplement to the San Francisco water supply which comes from the Hetch Hetchy Reservoir and they are used only intermittently.

Two hospitals for tubercular patients are located approximately five miles southwest of the facility. There is one sanitarium for mental patients and a general hospital in the town of Livermore. A new city hospital is due to be built at the western edge of Livermore in two years.

2.2. POPULATION DENSITY

The main population centers are located in a westerly direction from the reactor site. The largest population center is the town of Livermore about 3 miles distant from the reactor. In 1950 the Census Bureau reported the population of Livermore to be 4,364. Present estimates put this figure at 12,000. About 10 miles in a westerly direction from the reactor is located the town of Pleasanton which had a population in 1950 of 2,244 and a present population of 3,900. Three other small towns are also located within 10 miles of the site. These are Dublin, approximately ten miles distant, with a population of 150; and Ulmar, approximately one and one-half miles distant, with a population of 200. Many small homes and farms are situated on the highway and in foothills in the western portion of the valley. The total population of the valley can be estimated from the populations of Murray Township and Pleasanton Township. Estimates from the 1950 Census put the population of Livermore Valley at approximately 13,400. Using the present estimates, the total population in the valley is 27,500.

2.3. METEOROLOGY

Wind speed and directional roses prepared by the U. S. Weather Bureau indicates that most probable daytime winds are those with a southwest direction. A pronounced west peak exists in the summer half year and a northeast peak exists during the remainder of the year. These peaks are associated with two oppositely directioned seasonal regimes. During the summer the interior valleys are heated through the day, developing a large temperature differential between the air in the valleys and the relatively cool maritime air of the San Francisco Bay Region. The colder air then rushes inland. This phenomenon occurs almost daily with considerable regularity during the late spring and summer. During fall and winter the temperature gradient is directed in the opposite sense, and the flow from east to west through Altamont Pass produces a northeast wind frequency maximum, although this is less pronounced than is the summertime effect. Daytime wind speed during the year rarely exceeds 31 miles per hour and is normally less than 18 miles per hour. The maximum wind speed observed was 67 mph; no tornadoes or hurricanes have occurred.

The main difference between night winds and day winds appears to be the higher frequency of calms and a lower frequency of winds about 18 miles per hour at night. The location of the direction maxima is much the same.

No data are available for winds aloft at Livermore. At Oakland, however, ground wind speeds are comparable to wind speeds at 500 meters and 750 meters with a slightly higher NNW and NW direction frequency.

Although no radiosonde records are available for this region, the Weather Bureau has predicted that unstable conditions will predominate during the day with isothermal or inversion conditions during the night. Because of the somewhat high frequency of low strata during the summer nights, more frequent isothermal or even unstable conditions beneath the cloud base can be anticipated than would be found if the nights were all clear. A low-level inversion layer, associated with the Great Basin Anticyclone, might persist in the valley for a number of days during the winter months.

The weather, in relation to the operation of the facility in the Livermore Valley is generally favorable. The winds blow directly towards Livermore, the closest large center of population, only 9% of the time during the year. During periods of precipitation, the wind blows towards Livermore only 6% of the time. The rainiest month, January, averages only eleven rainy days. These conditions greatly reduce the probability of any contamination in the town of Livermore.

A more detailed description of the meteorology of the region is given in Appendix A.

2.4. SEISMOLOGY

In 1925, by Act of Congress, the U. S. Coast and Geodetic Survey assumed responsibility from the U. S. Weather Bureau for collecting and publishing earthquake data. There has thus been provided a continuous record of observed reports of earthquake motion in the United States. In California, the Seismological Field Survey of the U. S. Coast and Geodetic Survey, has collected additional information over the period from 1933 to the present, which has been analyzed by many in the interests of a better understanding of the engineering problems arising from earthquake phenomena.

A perusal of the records of earthquake observations at Livermore shows that for the period 1925-1953, 53 earthquakes occurred within a five-mile radius of Livermore, also, there have been 21 additional reports of felt earthquakes. Two-thirds of the total number occurred in a five-month period in 1943. The next highest frequency was in 1946 when three earthquakes were reported. The intensity has been short of damaging (V or less, Modified Mercalli Scale of 1931) throughout this period.

Of the 21 additional reports, 15 were of intensity VI (Modified Mercalli Scale,) or greater at the epicenters which were within a 100 mile radius. Again, these represented intensities less than damaging (V or less) at Livermore. An additional 15 shocks of intensity VI or greater occurred within a 100 mile radius for which no felt reports were obtained from Livermore.

2.4.1. Earthquake Effects Prior to 1925

Information is limited for this period, even for moderately severe earthquakes. Early records report a major earthquake observed in California as occurring on January 9, 1857. The seat of the disturbance was in the Southern Coast Range from Chalame Valley to the San Bernardino Valley, 225 miles in all. Since it was felt as far east as Sacramento and was severe in San Francisco, presumably it would have had appreciable intensity in Livermore.

Moderately severe shock occurred on October 8, 1865, and on April 24, 1890, south of San Jose. In the light of recent data, it is doubtful if significant intensity reached Livermore. On October 22, 1868, the Hayward fault between Oakland and San Jose was the seat of earth movements which produced an intensity of X (Rossi-Forel) at the vicinity of the fault trace near Hayward. There is no question but that this shock was felt appreciably in Livermore.

April 18, 1906, ushered in the heaviest earthquake known to have occurred in California. The point of maximum intensity (head of Tomales Bay) occurred some 70 miles northwest of Livermore. The effects at Livermore were described in these words:

> "Many chimneys were cracked ... Several tall brick chimneys ... were left intact. Those on brick piers ... were undamaged. A block of old weak looking buildings ... no more than a few cracks. Glassware ... was thrown to the floor in quantity in various directions. A heavy water tank at the depot fell, owing to weakness of supports. Concrete bridges about town were unhurt."

2.4.2. Probable Seismicity

Gutenberg & Richter list 80 California earthquakes of intensity VI (Modified Mercalli Scale) or greater for the period 1904-1946. The acceleration associated with earthquake motions varies inversely as the square of the distance from the epicenter and directly as the square root of the energy released. Based on the analysis of strong motion accelerograph records of 14 West Coast earthquakes and the assumptions that California earthquakes have the same occurrence pattern as world earthquakes, Housner states that earthquakes of the magnitude of

San Francisco, 1906, or greater are not expected to occur in California more often than once in 200 years on the average. It is also shown that the probability is once in 75 years that a specific area is expected to experience ground motion of the intensity of El Centro (1940) or Long Beach (1933) or greater (7.5 Modified Mercalli Scale). An estimate of 0.66 times gravity is given for the maximum ground acceleration that may occur. It must be mentioned that these conclusions are of an empirical nature.

2.5. GEOLOGY

There are two theories as to the formation of the Livermore Valley. One claims the valley was formed by erosion and dissection as the region around the valley experienced an uplift during buckling and warping of the earth's crust. The second theory indicates the valley was formed by great faults that let the ground surface fall several thousand feet. Both theories of formation, however, lead to the development of a large bowl filled with water-bearing gravel (Pliocene) and sealed on all sides to the passage of underground water from the valley. Because of relatively heavy rains during the rainy season and the steep sides presented by the newly formed valley, large quantities of coarse gravel were washed into the floor of the Arroyo del Valley, Arroyo Mocho, Arroyo Las Positas, and other drainage areas, leaving a second layer of water bearing gravel on top of the Pliocene gravels. This latter process is still occurring but, as the valley has filled, the streams have become more meandering on the valley floor and the large gravels have, of recent years, been deposited on the eastern edge of the valley while only the silt is carried to the Pleasanton side. This has resulted in a 30-40 foot silt cap on the eastern edge, gradually decreasing in thickness, until at Livermore, the coarse gravel is apparent in surface outcroppings.

Water percolates these surface gravels easily (approximately 10 cubic feet of water per square foot of superficial surface per day) and the gravel beds rapidly saturate each rainy season. Relief, after filling, is provided by seepage to the surface through the silt cap at the eastern end of the valley and outlet to the sea via the Niles Gap. No underground water escapes via the San Ramon Valley. During the summer months the water table is lowered by pumping and by evaporation. At the surface, evaporation from the water table can account for 45 inches per year; however, this rate drops to zero at a water table level of nine feet. Water passage through the gravel bed is estimated at 30 feet per day under free flow. The actual flow, however, will be dictated by pumping demands, evaporation from the lower valley, and filling of the gravel bed during the stormy season.

A more detailed description of the geology of the region is in Appendix B.

III. BUILDING DESCRIPTION

The Building 110 complex contains two areas which have been designed for sub-critical and low power critical experiments. These two areas are distinguished from each other principally by their manner of containing airborne contamination. The description of the buildings will be done along the lines of this distinction.

3.1. THE CONTAINMENT BUILDING

One point should be made clear at the very beginning of the discussion of this area: The new critical test facility of LRL is in a containment structure because it is the policy of the laboratory to take every reasonable precaution to prevent hazards to employees and the public from occurring as a result of their operations. The containment shell is designed to make a relatively conventional critical facility as safe as present techniques can make it - it is not the result of a desire to make possible extremely hazardous and marginally safe operations. When the first vaults were designed in 1953, they embodied all of the safety features that were in use anywhere at that time. By 1958, when the new cell was designed, the knowledge and experience of the critical assembly group personnel and the general experience of the nuclear industry made possible the design and construction of a facility which embodied all of the safety features used in advanced power reactor installations, with little more cost than for a conventional critical test cell. This facility should be as effective in preventing release of radioactive and toxic products to the atmosphere as any reactor containment facility. This means, since a critical assembly never has but a minute fraction of the fission product inventory of a reactor, that the operation is orders of magnitude less hazardous to the public. The shielding, ventilation, monitoring and experimental conveniences should make it at least as safe for the operators as any critical operation in the world.

3.1.1. Building Structure

The new large assembly area is housed in an air tight containment structure which was designed to prevent the release of any radioactive or highly toxic material to the atmosphere. This containment structure was designed and constructed to withstand internal pressures of two p.s.i. which could result from temperature and barometric changes while it is sealed. The floor plan of the building is shown in Figure 3-1 and the elevation in Figure 3-2. The containment area is 40 feet high and 78 feet in diameter. It is divided into two halves, one unshielded and the other shielded. The shielded half, in which all assembly work with fissionable material will be done, is a semi-circular room with concrete walls five feet thick. The ceiling is of concrete and is two feet thick. Head room above the floor level in this vault is twenty feet. A door ten feet square provides truck access to the vault. It is closed by a five foot thick concrete door. The remainder of the building, i.e. the domed roof and cylindrical east wall, are made of 1/4" thick steel plate. The unshielded half of the building has a ten foot square steel door to provide truck access. Each half of the building has a ten foot deep pit approximately 30 x 30 feet. This pit is covered with a light metal grating. This provides an experimental area where neutron return from the floor and walls is minimized. For work with unreflected assemblies or for transient measurements on sub-critical assemblies made with pulsed neutron sources such an area is very desirable.

3.1.2. Features to Insure Containment

In order to assure the air tight feature of the containment building, the following special precautions have been taken:

1) The personnel passage between the control room and the containment building is through an air lock.
2) Both truck doors and both air lock doors are sealed with inflatable rubber gaskets.
3) All conduits for experimental cables entering the building are cast in concrete which is part of the building foundation. The space around the cables in the conduits will be sealed with internal packing.
4) All pipes and conduits for power cables entering the building are welded to the steel shell. The electrical conduits have internal packing to prevent leakage down the conduits. All pipes are provided with manually operated valves which can be closed, if desired, to prevent leakage down the pipes.
5) Leakage past the steel shell-concrete foundation junction is prevented by a double compression gasket and calking compound.

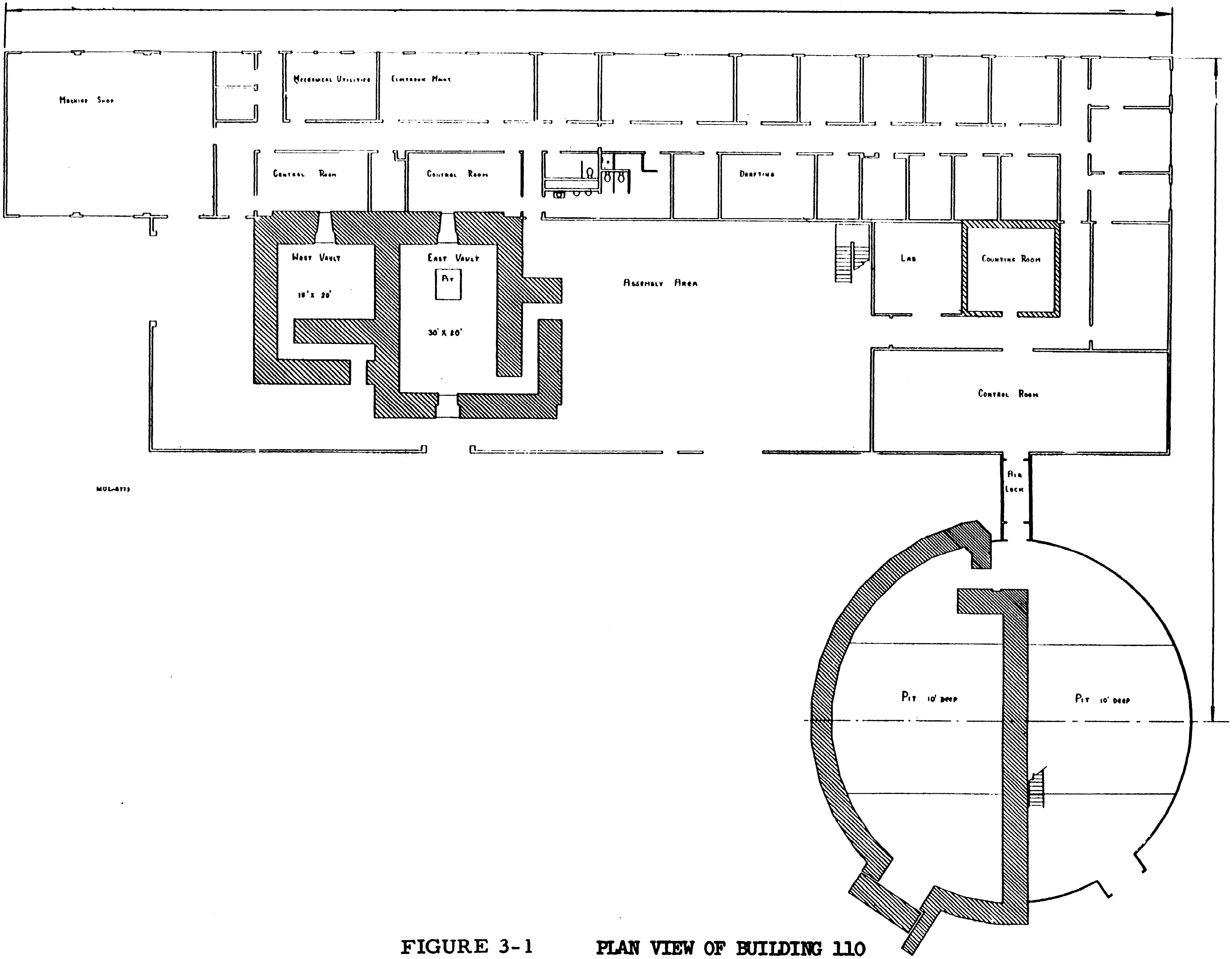
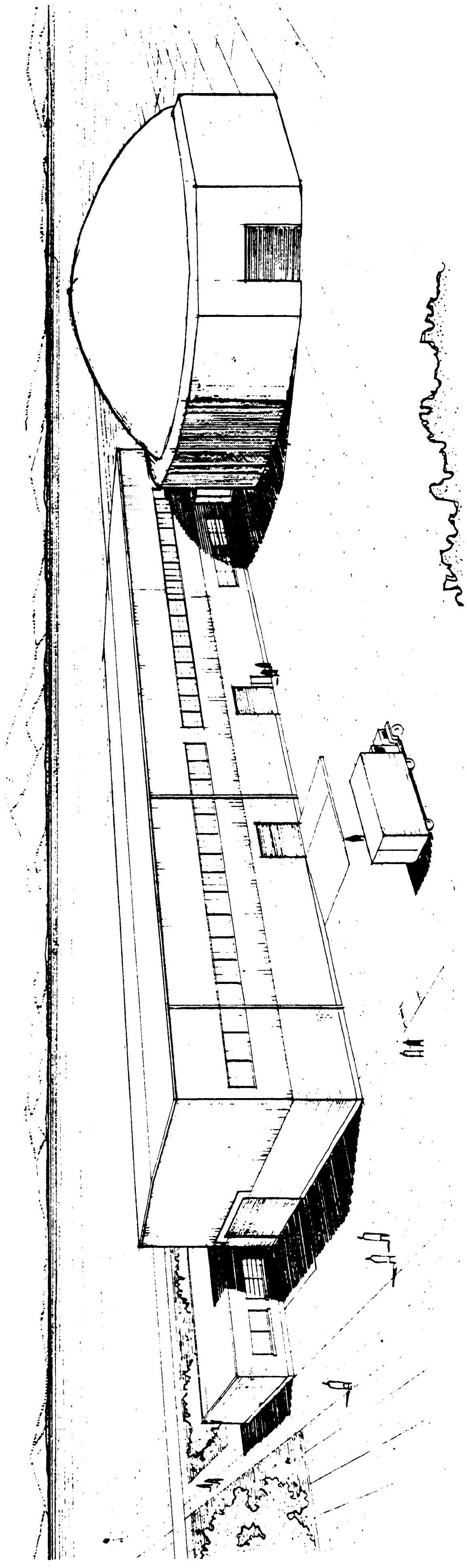


FIGURE 3-1 **PLAN VIEW OF BUILDING 110**



6) The intake and outlet of the ventilation system are provided with quick acting normally closed butterfly valves which seal these openings. All air conditioning and ventilating equipment is inside the building.

Upon completion of construction various leak tests were made upon the building. The building was pumped to 2 p.s.i., sealed and the leak rate measured. The building was also sealed at atmospheric pressure and the leak rate measured as temperature and barometric changes occurred. In both cases the leak rate was less than four per cent of the volume per twenty-four hour period, over a two day test period.

A building of this size could, when sealed, develop external pressures which could cause the steel shell to buckle. To prevent such an occurrence, a relief mechanism is provided to bleed air into the building if the external pressure exceeds the internal pressure by more than two ounces per square inch. This mechanism consists of a Shand-Jurs relief valve mounted on the north portion of the steel shell above the air lock.

3.1.3. Ventilation

The containment building is fully air conditioned by two internal air conditioning units which service the two halves of the building. A 20 ton unit services the unshielded half. Due to the smaller heat leak to the vault, a 10 ton unit is sufficient for this area. No effort has been made to seal the two sides of the building from each other, so air from the two systems can be mixed as desired.

The ventilation system brings in outside air to provide about ten per cent of the total volume circulated and a like amount is exhausted to the outside. The incoming air is filtered to remove dust before entering the system. The air exhausted to the outside is passed through a Cambridge CWS high efficiency filter before leaving the building. The recirculated air goes through a filter on each pass through the system. This filter is also a Cambridge CWS high efficiency filter. These filters remove particles down to 0.3 microns diameter with an efficiency of at least 99.95%. There is thus a continual cleanup of the air within the containment building and all exhaust air must pass through a high efficiency filter before leaving the building.

The valves which seal the building are standard quick acting Pratt butterfly valves which are actuated by a signal from the control console. They can be closed either by a manual "building seal" signal or by any desired unit of the safety chain. They will normally be closed by only two signals; the manual signal and the signal from the monitor in the exhaust air duct. When the valves are closed, the air conditioning system continues to operate and the system becomes a recirculating system where the air goes through a high efficiency filter on each pass. The volume of the building is approximately 200,000 cubic feet and the ventilation system will recirculate approximately 3,000 cubic feet per minute. There is thus about one pass of the building air through the filters each hour.

A schematic diagram of the ventilation system as it is for normal operation is shown in Figure 3-3. Upon receipt of a building seal signal, the various motor dampers operate to produce the flow pattern shown in Figure 3-4.

The air leaving the building is sampled for radioactive particulate matter. The detector is a Nuclear Measurements Corporation Model FGM-1 which is sensitive to alpha, beta and gamma radiation. Should the level of activity in the exhaust air exceed the prescribed level, this monitor will seal the inlet and outlet valves and signal this event in the control room. The trip level will be set by the Hazards Control group of the laboratory. In general, the alarm will be set to trip at a counting rate corresponding to the activity collected by sampling air containing twenty-five times the maximum permissable limit of fission products for one minute. Since a building seal does not distrub the experiments being conducted, the trip level can be set very close to the natural radon background level.

3.1.4. <u>Decontamination</u>

All exposed surfaces in the containment building have been treated to facilitate decontamination in the event it should be required. The vertical concrete surfaces and the concrete ceiling in the vault have been plastered and then sprayed with several coats of white strippable plastic paint. Floor surfaces have been painted with several coats of

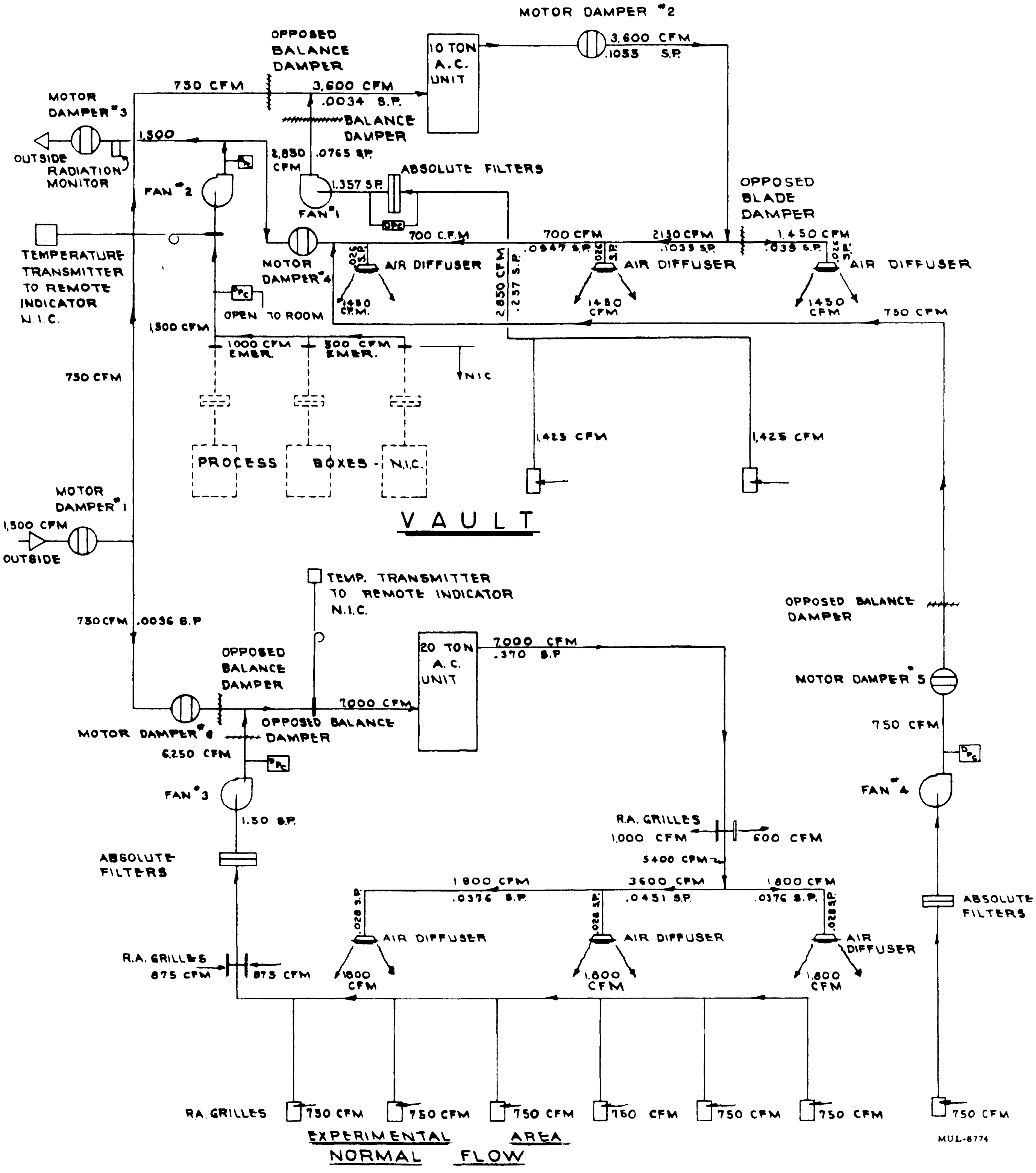

MOTOR DAMPER #2
OPPOSED BALANCE DAMPER
10 TON A.C. UNIT
3,600 CFM .1055 S.P.
750 CFM
3,600 CFM .0034 S.P.
BALANCE DAMPER
MOTOR DAMPER #3
1,500
OUTSIDE
RADIATION MONITOR
2,850 CFM
.0765 S.P.
ABSOLUTE FILTERS
1.357 S.P.
FAN #2
FAN #1
OPPOSED BLADE DAMPER
TEMPERATURE TRANSMITTER TO REMOTE INDICATOR N.I.C.
MOTOR DAMPER #4
700 C.F.M
700 CFM .0947 S.P.
2150 CFM .1039 S.P.
1,450 CFM .039 S.P.
AIR DIFFUSER
1450 CFM
2,850 CFM .237 S.P.
750 CFM
OPEN TO ROOM
1,500 CFM
1000 CFM EMER.
500 CFM EMER.
N.I.C.
750 CFM
1,425 CFM
PROCESS BOXES - N.I.C.
MOTOR DAMPER #1
1,500 CFM
OUTSIDE
VAULT
TEMP. TRANSMITTER TO REMOTE INDICATOR N.I.C.
OPPOSED BALANCE DAMPER
750 CFM .0036 S.P.
20 TON A.C. UNIT
7,000 CFM .370 S.P.
7000 CFM
MOTOR DAMPER #5
MOTOR DAMPER #6
OPPOSED BALANCE DAMPER
6,250 CFM
FAN #3
FAN #4
1.50 S.P.
R.A. GRILLES
1,000 CFM
600 CFM
5400 CFM
ABSOLUTE FILTERS
1,800 CFM .0376 S.P.
3600 CFM .0451 S.P.
1,800 CFM .0376 S.P.
.028 S.P.
AIR DIFFUSER
R.A. GRILLES
875 CFM
875 CFM
1,800 CFM
R.A. GRILLES
750 CFM
EXPERIMENTAL AREA
NORMAL FLOW
MUL-8774

FIGURE 3-3

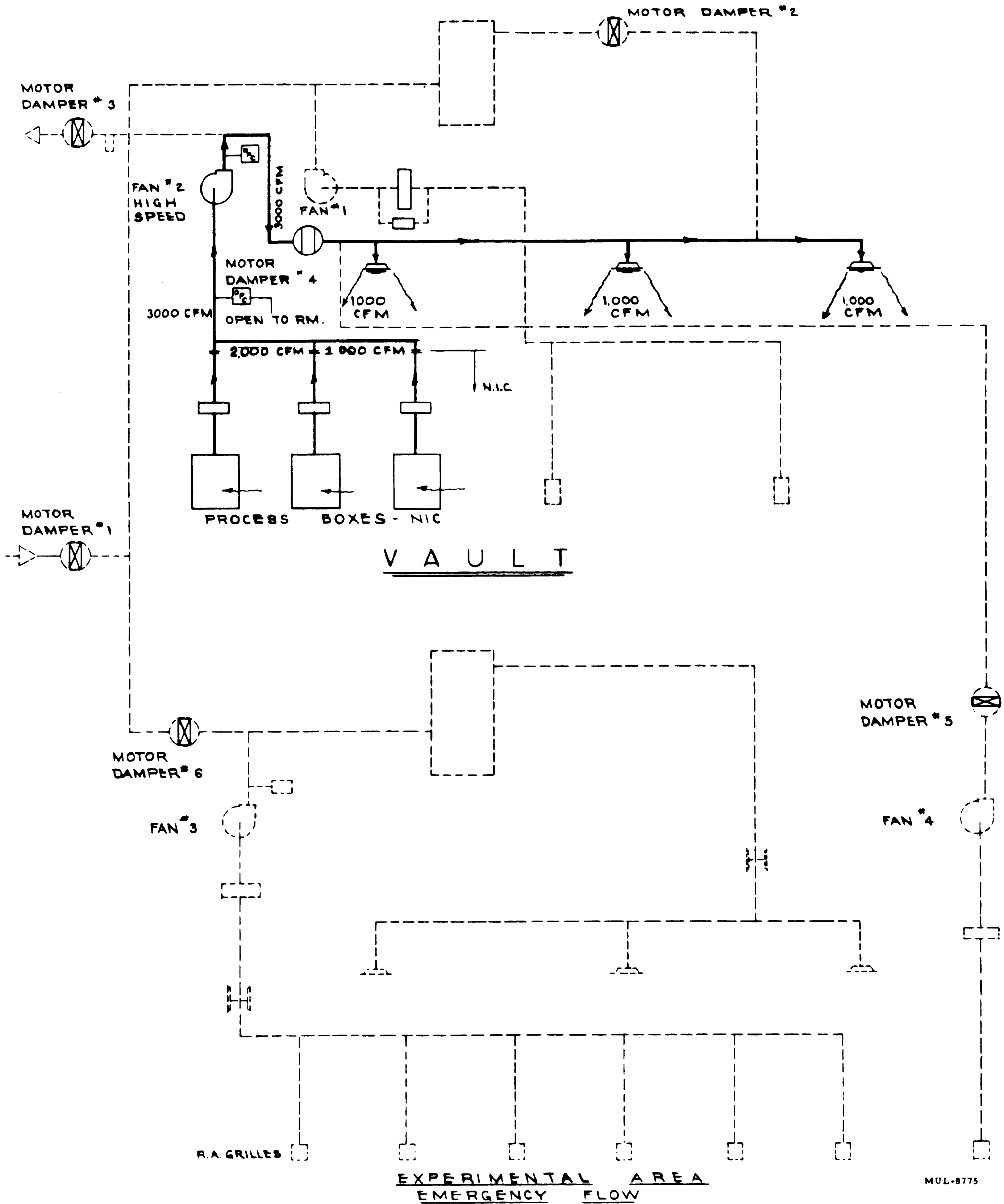

MOTOR DAMPER #2
MOTOR DAMPER # 3
FAN # 2 HIGH SPEED
3000 CFM
FAN # 1
MOTOR DAMPER # 4
OPEN TO RM.
3000 CFM
1000 CFM
1,000 CFM
1,000 CFM
2,000 CFM
1 000 CFM
N.I.C.
PROCESS BOXES - NIC
MOTOR DAMPER #1
VAULT
MOTOR DAMPER # 5
MOTOR DAMPER # 6
FAN # 3
FAN # 4
R.A. GRILLES
EXPERIMENTAL AREA
EMERGENCY FLOW
MUL-8775

FIGURE 3-4

Bisonite. These floors include the pit floors and the top surface of the vault roof. The steel surfaces which make up the east wall the the roof of the building have been covered with two inches of glass wool thermal insulation bonded to a polyethylene sheet which faces the interior of the building. Thus, all exposed interior surfaces of the building itself can be washed, or in extreme cases, stripped and replaced.

3.2. THE EAST VAULT

The East vault is one of the original experimental areas constructed in 1954. It was used for a variety of sub-critical assemblies on metal uranium and plutonium systems during 1954 and 1955. Since 1956 it has been used almost exclusively for an extensive series of critical measurements on heterogenous cores of graphite and oralloy, and beryllium oxide and oralloy. This vault was not designed to be a containment type structure, but care was taken in the design to prevent the spread of contamination which might be produced in the vault during normal operation, or which might follow a prompt burst in a critical assembly. The floor plan of the vault is shown in Figure 3-1.

3.2.1. Structure

The East vault is 20' x 30' x 12 1/2'. The north and west walls of the vault are five foot thick normal density concrete. The south and east walls are formed of two courses of normal density concrete blocks, stacked to minimize straight line openings through the wall. The blocks are grouted together, and Monterey sand has been used to fill all interstices. These walls are also five feet thick. The roof of the vault is presently composed of timbers which are two feet thick. It is planned to replace these timbers with concrete beams thirty inches thick during FY 1961. The ventilation system is to be replaced at the same time. When these modifications are complete, the roof shielding and ventilation system will be the same as that now on the West vault.

3.2.2. Access

Personnel access is provided by a maze on the east side. The maze has two right angled turns between the building and the vault. The vault end of the maze is closed by a one hour bank vault door. At the building end the maze is closed by a light wooden door, which forms part of the safety chain for the area. This door must be opened by a key from the control console. Removing this key opens the safety chain. When the door is opened, a microswitch on the door also interrupts the safety chain.

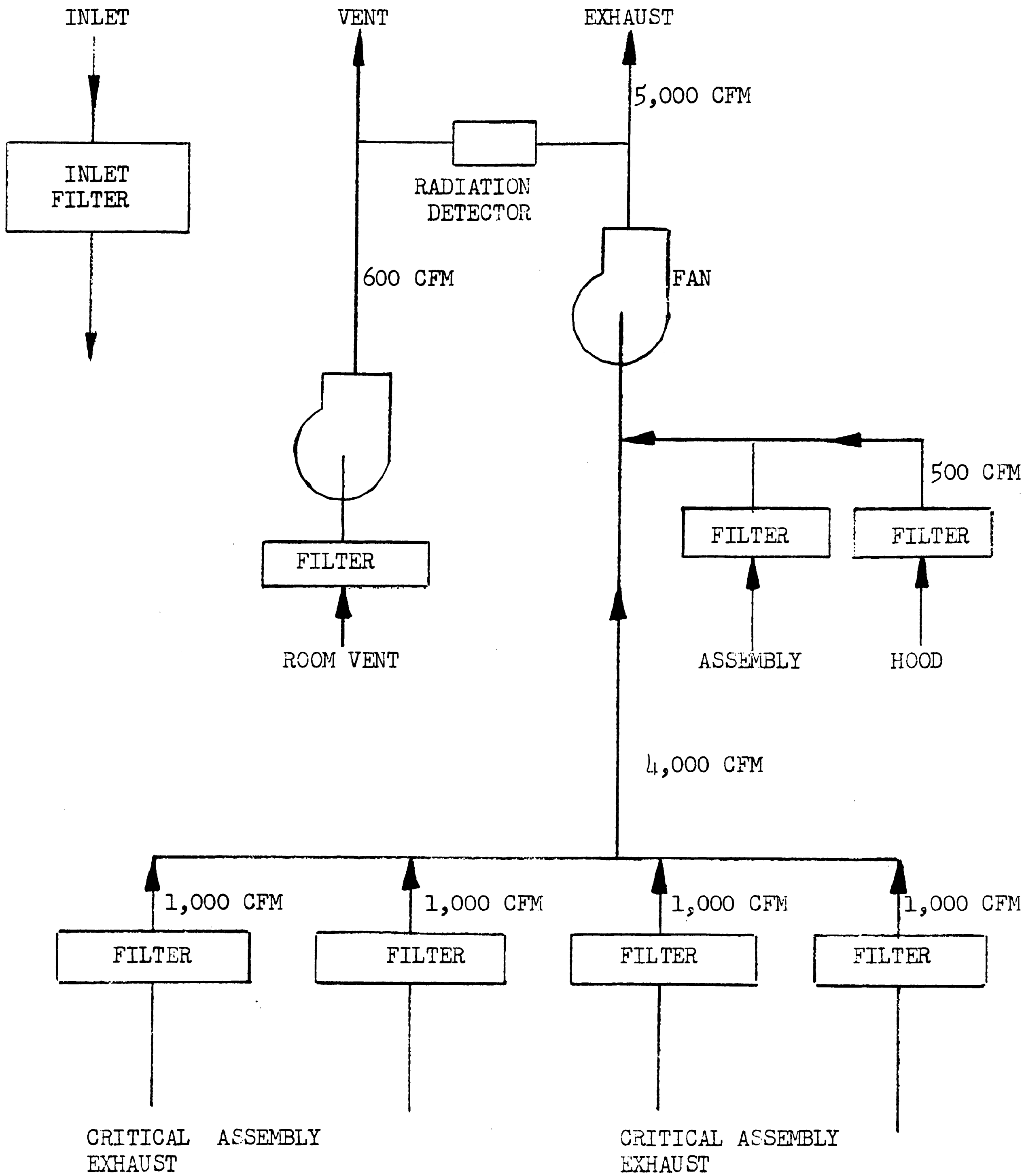
Access is provided in the south wall for a small fork lift through a movable water door. This door is six feet thick and closes an opening which is 5' x 7-1/2' on the outside and 4' x 7' on the inside. A step in the door around both sides and the top prevents radiation streaming through the crack between the door and wall. The door is mounted on wheels and can be pulled back onto a concrete pad outside the building to allow material to be brought into the vault. Switches on the door insure that it is in place before the safety chain can be completed.

3.2.3. Observation

Visual observation of the interior of the vault is provided by a water window in the north wall. This window is six feet thick. It has a 4' x 4' opening in the vault and tapers to a 30" x 18" opening in the control room with a step in the middle of the wall. It provides a clear and undistorted view of the interior of the vault for the operator. The glass on the vault side is protected by a one inch thick piece of lucite which acts as a splinter shield in the event of a violent excursion. It also serves to protect the glass against breakage during installation and maintenance of equipment in the vault. The glass in the control room window is protected by a one-half inch thick lucite shield. Both panes of glass are one inch thick Tuflex glass which is treated for extra strength. Water capacity of the window is approximately 500 gallons.

3.2.4. Ventilation

The ventilation system for the East vault is shown in Figure 3-5. This system is completely independent of the system for the West vault and cross contamination of the two areas cannot occur through the ventilation system. The system is designed to provide a dynamic seal on the vault by insuring that air leaks into the vault during normal operation. In order to make this seal as effective as possible, all openings other than the system air inlets and outlets have been



EAST VAULT VENTILATION DIAGRAM

FIGURE 3-5

sealed. The conduits leading to the control room are sealed at the vault end. The door to the maze is not air tight, but it is a close fitting bank vault door and leakage around the door is small. The individual roof timbers are wrapped with polyethylene sheet and the cracks between timbers are covered with plastic tape.

Air enters the vault through an opening covered with a Type PL Class I American Air Filter Company filter. This filter is designed to remove dust from the incoming air. In addition, since the filtering action is the same regardless of the direction of air flow, this filter would remove much of the airborne particulate matter from air forced from the vault should an over pressure ever occur.

Air is exhausted from the vault through two separate systems and stacks. One system provides general room ventilation at all times. The other system provides air flow through process boxes and hoods and may or may not be operating at any given time, depending on the work being done. All air exhausted through either system passes through Cambridge CWS high efficiency filters before being released to the atmosphere. These filters remove 99.95% of all particles greater than 0.3 microns in diameter and represent the best obtainable filters. The stacks release the exhaust air at approximately 50 feet above the ground.

An alpha particle monitor samples the discharge air after it leaves the filters. The sampled air is drawn through a millipore filter paper which removes the particulate matter. A two inch photomultiplier tube coated with zinc sulfide looks directly at this paper and counts the alpha activity. The signal from the tube is fed to a count rate meter and recorder in the control room. An alarm bell and light warns the operator when the level exceeds any pre-set amount.

3.2.5. Decontamination

The vault is designed to make decontamination as feasible as possible in the event of contamination with radioactive material during normal operations or following a critical accident. The floor of the vault is covered with vinyl linoleum, which is waxed.

This is washable with almost any desired solvent, and in extreme cases it can be stripped from the floor. The walls are covered with two coats of expoxy resin over glass cloth. Over this are painted two coats of strippable white Amercote paint. This gives a surface which is impervious to water and most solvents. The paint can be stripped in cases of heavy contamination. The roof timbers are individually wrapped in polyethylene sheet. The cracks between the timbers are sealed with four inch wide plastic tape. In the event of ceiling contamination, the plastic would be stripped from the timbers.

Operating experience with large quantities of thin oralloy foils has indicated that during normal operations very little contaminated material escapes from the ventilated hoods which are kept over the handling areas. The material which does escape causes low order contamination on the floor areas, and not on the walls or ceiling. The floor contamination has been easily cleaned up with soap and water, due to the smooth, impervious nature of the waxed linoleum.

3.3. THE WEST VAULT

The West Vault is the second of the two original experimental areas constructed in 1954. It was originally very similar to the East Vault described in section 3.2., except in size, being only 15' x 20' x 12-1/2'. It has, however, since undergone extensive modifications designed to increase its safety, as is described in the following sections.

This vault, due to its small size, has been used exclusively for measurements on small systems, chiefly those with uranium and plutonium cores. Some work has been done on solutions of U^{233} in this test cell also. At present, installations for the Kukla program are being made. These are described in detail in a classified hazards report for this program: Document COVA-555.

3.3.1. Structure

The West Vault is 15' x 20' x 12-1/2'. The north and east walls of the vault are five foot thick normal density concrete.

The south and west walls are formed of two courses of normal density concrete blocks, stacked to minimize straight line openings through the wall. The blocks are grouted together, and Monterey sand has been used to fill all interstices. These walls are also five feet thick. The roof of the vault is composed of "T" shaped concrete beams 30 inches thick. They are stacked to eliminate straight through cracks. Removable plugs are provided for air ducting and instrumentation cables.

3.2.2. Access

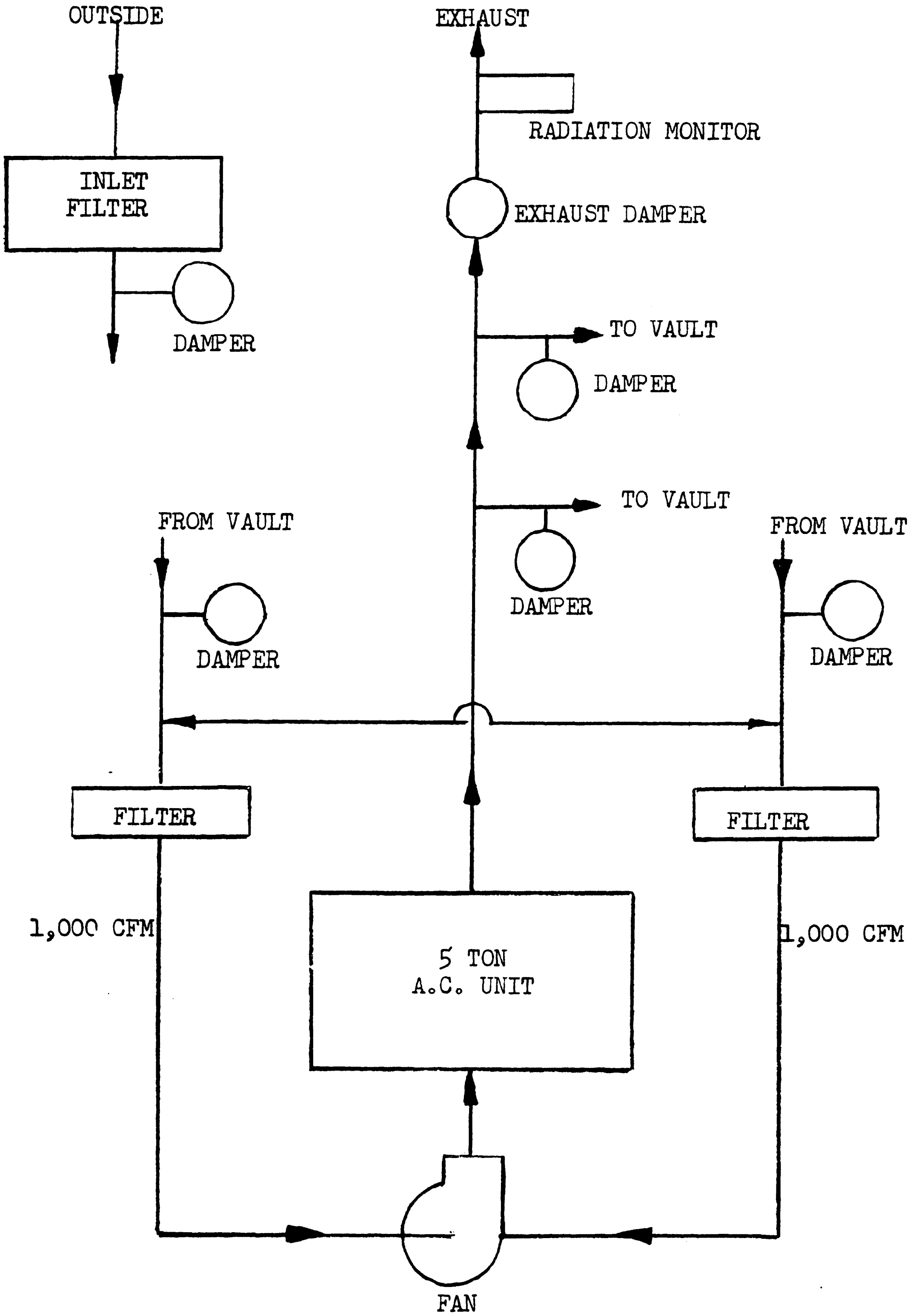
Personnel access is provided by a 40 inch wide maze on the south wall. The maze has two right angled turns twenty feet apart between the vault and the building. The vault end of the maze is closed by a one hour bank vault door. At the building end the maze is closed by a light wooden door, which forms a part of the safety chain for the area. This door must be opened by a key from the control console. Removing this key opens the safety chain. When the door is opened, a microswitch on the door also interrupts the safety chain. No other access to the test cell is possible except through the maze.

3.2.3. Observation

Visual observation of the interior of the vault is provided by a water window in the north wall. This window is six feet thick. It has a 4' x 4' opening in the vault and tapers to a 30" x 18" opening in the control room with a step in the middle of the wall. It provides a clear and undistorted view of the interior of the vault for the operator. The glass on the vault side is protected by a twelve inch thick piece of lucite which acts as a splinter shield in the event of a violent excursion. It also serves to protect the glass against breakage during installation and maintenance of equipment in the vault. The glass in the control room is protected by a six inch thick lucite shield. Both panes of glass are one inch thick Tuflex glass which is treated for extra strength. Water capacity of the window is approximately 500 gallons.

3.2.4. Ventilation and Containment

The ventilation system for the West Vault is shown in figure 3-6. This system is completely independent of the system for the East



WEST VAULT VENTILATION DIAGRAM

FIGURE 3-6

Vault, and cross contamination of the two areas cannot occur through the ventilation system. The system contains an air conditioning system to prevent the reactivity changes associated with temperature changes which would occur in the metal systems which usually occupy this cell.

The system is designed to maintain a dynamic seal on the vault by maintaining a slight negative pressure in the vault. In order to make this seal as effective as possible, and also to prevent diffusion of any activity in the vault in the event the system is off, several steps have been taken to seal the opening in the cell. Air tight seals have been installed around the ducting and cable conduits which penetrate the roof. Conduits leading to the control room contain packing around the cables to seal them. The walls and ceiling have been painted with a continuous coat of Ply-On plastic paint. This paint forms a thick strippable plastic coating which seals all cracks and other small openings. The floor is covered with vinyl linoleum. All ventilation openings can be closed with dampers operated from the control room. The effect of these various steps has been to produce a cell for which the only leakage path is around the very close fitting bank vault door which leads to the maze. The vault is not a containment unit in the sense that it is designed to hold positive internal pressures for long periods, but it offers a leakage area of no more than a few square inches, when the door and dampers are closed.

The ventilation system exhausts air through a Cambridge high efficiency filter into a stack which vents 50 feet above the ground. The system contains six pneumatically operated dampers which can be used to close off whatever part of the system is desired. All dampers are operated from the control room. One of these is on the outside fresh air inlet, two on the openings where conditioned and filtered air is returned to the vault and two on the openings where air is taken from the vault into the system. These five dampers are connected to the instrument air supply of the laboratory. A standby supply provided by a nitrogen gas cylinder can be manually switched into the system. In the event of a failure of both gas supplies, the damper springs close the dampers.

There is one other damper in the exhaust line to the outside. This unit is connected to the same gas supply as the other five. It is a spring loaded, normally closed damper. The system thus has two sets of dampers which can seal the vault and prevent material from being discharged through the stack. Normal emergency operation would be with all dampers open. If the radiation monitor indicates radioactive matter in the exhaust air, the exhaust damper can be closed. The system now recirculates 2000 cfm through high efficiency filters to clean up the vault air. If the exhaust damper should fail to operate or seal, the vault damper can be used to prevent leakage. However, since this would prevent the clean up action of the system, such a procedure would be used only in extreme cases.

The dampers which face the vault are 1/2-inch thick steel, with two inches of sponge rubber on the vault side. They close against the roof of the vault and overlap the opening in the roof by two inches on all sides. They are designed to preserve the integrity of the ventilation system against any missiles developed in a severe accident in the vault.

The air which is exhausted from the vault is sampled for radioactive particulate matter by a Nuclear Measurements Corporation Model FGM-1 air sampler. It is sensitive to alpha, beta and gamma radiation.

Should the level of activity in the exhaust air exceed the prescribed level, this monitor will close the exhaust damper and signal this event in the control room. The trip level will be set by the Hazards Control Group of the laboratory. In general, the alarm will be set to trip at a counting rate corresponding to the activity collected by sampling air containing twenty-five times the permissible limit of fission products for one minute. Since closing the exhaust damper does not disturb the experiments being conducted in the cell, the trip level can be set very close to the natural radon background level.

3.2.5. Decontamination

The vault is designed to make decontamination as feasible as possible in the event of contamination with radioactive material during normal operations or following a critical accident. The floor is covered with vinyl linoleum, which is waxed. This is washable with almost any solvent, and in extreme cases it can be stripped from the floor. The walls and ceiling are covered with an integral coating of Ply-On plastic paint. This is a thick, tough coating of plastic which can be stripped if necessary.

IV. ADMINISTRATIVE PROCEDURES

The work of the Lawrence Radiation Laboratory is such that assemblies of fissionable material or chemical and mechanical processes dealing with fissionable material are carried on almost continually. There is consequently a continual problem of nuclear safety at the laboratory and the operation of the critical assembly facility represents only one area where attention must be given. The primary responsibility for the establishment of measures designed to prevent the attainment of accidental criticality lies with the members of the Critical Assembly Research Group (CARG). The procedures used within the critical facility differ from those used throughout the laboratory only in that they are undertaken with the intent safely to construct systems which are critical or near critical. Those used in the remainder of the laboratory are intended to assure that attainment of even near criticality is not possible without a coincident failure of at least two of the safety features. Much of the following description of administrative processes is applicable to both the critical facility and to process areas within the laboratory.

4.1. RADIATION MONITORING

The personnel monitoring program at Building 110 provides conditions and controls to assure that no employee is exposed to doses of radiation or of radioactive material in excess of the recommended maximum permissible exposure. A health physicist is on duty during the normal work day to help the experimental staff in radiological safety. Two types of individual monitoring devices are worn (1) pocket (ionization chamber) dosimeters reading 0-200 mr of gamma and (2) film badges. The film badges have Du Pont 558 packet beta-gamma film and Eastman NTA neutron film. Aluminum, cadmium, and lead shielding strips are used to allow determination of the energy of the gamma radiation. The sensitive film reads from about 10 mr to 3R and the emergency film determines exposures of 2 to 1000 R. The beta-gamma films are changed weekly while the neutron films are used for two weeks. The films are color coded and attached to the security badge so they are changed at least once a month. There are six film packets at various positions inside and outside the vaults to determine general background. A fission threshold detector system based on the work of Hurst at ORNL is placed in each cell in case of a criticality accident. The detectors are Pu^{239}, Np^{237}, U^{238}, sulfur, and two gold foils, one bare and the other cadmium covered.

Hand and foot counters designed and manufactured by LRL are used to prevent the spread of contamination. The alpha sensitivity is 200 to 20,000 cpm and the beta-gamma counter measures 0.01 to 1 mr. per hour. Protective clothing, respirators, gloves, and handling tongs are available when required. Standard portable survey instruments are used for radiation surveys of personnel and equipment. The following are available: (1) Nuclear and Eberline beta-gamma GM meters from 0.05 to 20 mr/hr. (2) Juno ionization chamber meter from 20 mr to 25 R/hr. (3) LRL air proportional alpha meters from 100 to 20,000 cmp. (4) Nemo BF_3 chambers neutron meter (both fast and slow) from 20 to 10,000 $n/cm^2/sec$.

Each of the three assembly areas have a Victoreen remote radiation monitoring system. The indicating and alarm meter is rack mounted in the control room. It has an alarm light, buzzer, reset button, and provision for remote calibration control with a standard strontium 90 source. There is an ionization chamber near the assembly machine and one at the entrance door. The logarithmic response covers a range from 10 mr/hr to 1000 R/hr. The new increment has a system with five stations to provide more complete coverage of the large vault.

All the air in the vault exhaust systems is passed through Cambridge CWS high efficiency filters, stopping 99.95 per cent of particles greater than 0.3 micron. A stack air sampler is installed in each exhaust line beyond the filters to detect filter failures and to prevent the discharge of airborne contamination into the atmosphere.

The air inside the vaults is monitored with LRL Filter Queen air samplers drawing four cubic feet per minute through thirty-two square inch HV70 paper. The papers are changed daily and can be read at any time to find high level contamination. After forty-eight hours radon thoron decay they are read again and can determine less than one per cent of an MPC. In the past year the airborne contamination in the two working vaults has exceeded an MPC one time. On this one occassion, which occurred during the counting and handling of several thousand oralloy foils, the level was less than three times the maximum permissible concentrations. Most of the time it is less than five per cent of an MPC. The east vault also has an ionization chamber fission product monitor sampling the air. The collected charge leaks to a vibrating reed electrometer through a 10^{12} ohm resistor. This meter can detect a concentration of about 10^{-6} microcuries per cc of mixed fission products or ten maximum permissible concentrations at any time.

4.2. MATERIAL CONTROL

The first prerequisite to the maintenance of nuclear safety is a clear understanding of who has fissionable material, how much they have and what they are going to do with it. This information is made available to the CARG during the preparation of the accountability manual by the responsible member of the project which is to use the material. No fissionable material is ever to be released from the central vault, following receipt, until the accountability manual covering its use has been completed. This document details the material to be used and outlines the processes and operations to be carried out. It specifies the precautions required for safe transportation and handling and designates the persons charged with the responsibility for seeing that all procedures given in the manual are followed. These are normally the persons who compile the manual; this insures that the project leader is thoroughly familiar with all requirements, since he will have originated them.

A Nuclear Safety Committee, consisting of the Division Leader, the Assistant Division Leader and four senior members of the Neutronics Division is available to consult with any member of the laboratory concerning criticality problems. The usual procedure is for the project head to present to the Nuclear Safety Committee the details of the process. Specifications are then worked out by the committee for batch limits, container sizes, work procedures etc. which will allow the program to be completed with the maximum safety comensurate with the actual carrying out of the work. Absolute nuclear safety can, of course, only be achieved by doing no work with fissionable material.

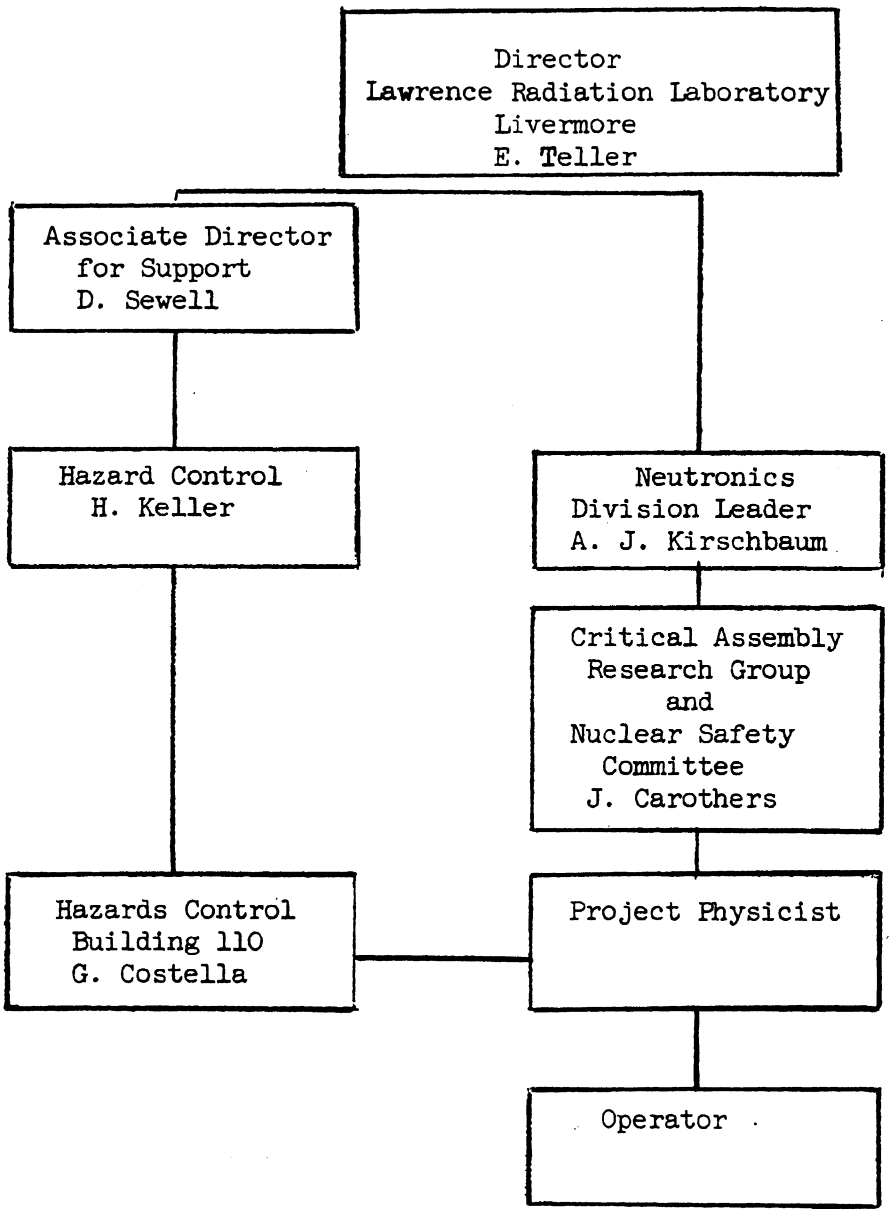
When the accountability manual is completed, it is approved by the heads of the Neutronics Division, Hazards Control, Accountability and the Associate Director for Support. This then constitutes authorization for release of material from the vault. This procedure insures awareness of all operations involving fissionable material, in any quantity whatsoever, by the CARG and by Hazards Control.

The administrative chain of responsibility is shown in Figure 4-1.

4.3. ASSEMBLY PROCEDURES

In addition to the preparation of the accountability manual by a project physicist within the Critical Assembly Research Group, the completion of a detailed and approved assembly procedure is required before any assembly work is done in the critical facility. This assembly procedure is written by the project physicist and represents his exact plan for the construction of the assemblies and the acquisition of the data necessary for the experiment. It gives the counters to be used, the counter checks that will be made, the type of assembly machine to be used, the various assemblies to be made and a detailed step by step procedure for making the assemblies. This procedure is approved by the Division Leader and Assistant Division Leader of the Neutronics Division and, contingent upon issuance of the proper accountability manual, constitutes authority for the experimental work to proceed.

Sections 5.2.7. and 5.3.7. are the assembly procedures which were written for the two typical programs used as examples for this report. These procedures were also incorporated in the accountability manuals for their respective programs. These accountability manuals could not be included since they are still classified Secret RD.



ADMINISTRATIVE CHAIN OF RESPONSIBILITY

Figure 4-1

4.4. RESPONSIBILITIES OF OPERATING PERSONNEL

The ultimate safety in any critical assembly program must be provided by the operating personnel. A critical assembly program differs in many very important respects from the day to day operation of a reactor. A reactor system, except for core or safety rod modifications, which are relatively infrequent, represents a stable, essentially unvarying system. Since the process is the same from day to day and even month to month, elaborate procedures and safety chains can be developed which make it essentially impossible for an operator, even with willful and deliberate intent, to cause more than a power excursion which would be contained within the safety factors designed into the system. A critical assembly system, on the other hand, is an experimental system where the basic experimental technique is one of increasing the reactivity through fuel or reflector increases. Since it almost always is necessary to bring the system to critical or to a very high multiplication and since this point is not precisely known in advance, excess fuel and or reflectors are always available in quantities sufficient to make the system far super prompt critical. The operator, if he wishes, can almost always construct a prompt critical assembly with ease, and no amount of procedural paper can stop him. To repeat at this point, the ultimate safety lies in the operator and the fact that he does not wish to make a prompt critical assembly. He must, in addition to not wishing to make a prompt critical assembly, have sufficient knowledge and understanding of the process to be able to evaluate at all times the data he has so he knows how critical the system is, how big a reactivity change the next step will cause and possible consequences of all forseeable contingencies. In order to help in this evaluation he is provided with a variety of instrumentation relevant to the experiment he is conducting. In order to assist him in the conduct of the experiment, well thought out procedures are prepared in advance of the actual work and he has them to refer to at all times. In order to protect him from the consequences of a mistake in evaluation, procedure or mechanical malfunction, safety chains are provided which will rapidly reduce reactivity in the event that a predetermined reactivity level is exceeded. And, finally, in order to protect him should all the above fail and a radiation burst actually occur, massive radiation shielding is provided to keep exposures in an accident to levels which are below a medical detectable level even in the event of a maximum credible accident.

All of these things are, however, only aids to the operator and he must actively make use of all of them to maintain the maximum level of safety. Consequently, the primary responsibility of all personnel in any assembly operation is to follow rigorously and with no exceptions whatsoever all procedures outlined in the approved assembly procedures and accountability manual. It is recognized that it is difficult to foresee all contingencies that might arise in an experimental program and that changes in procedures may be required in the course of the work. Such changes can be made, but only with the agreement of the Critical Assembly Group Leader and within the scope of the applicable accountability manual.

4.4.1. Critical Assembly Group Leader: This physicist is also the Assistant Division Leader of the Neutronics Division. The group leader assigns all personnel to the assembly programs. It is his responsibility to insure that procedures are written and approved as required. It is his responsibility to insure by personal inspection and knowledge that all proper procedures and practices are being followed at all times. He is the responsible custodian of all accountable materials and records pertaining thereto in the critical assembly research material balance area. He schedules all work in the assembly area and assigns relative priorities among the various programs. He is the head of the Nuclear Safety Committee.

4.4.2. Project Physicist: Every assembly program has a project physicist in charge of the program. He is assisted by a number of other physicists and operators, the number depending on the size and complexity of the program. The minimum number for any assembly work is two people at all times. It is the responsibility of the project physicist to prepare the assembly procedure and the accountability manual for his program and to obtain the necessary approvals. He must plan the experiments required and see that all necessary experimental equipment is designed, constructed, installed and operated properly. In this he is supported by the required engineering and shop effort. He must order the necessary fissionable material in the proper form. He must make any necessary calculations for the design of the experiment and for the support of the safety provisions of the assembly procedure. During the course of the experimental program it is his responsibility to insure that the data obtained is valid and sufficient for the program. He is responsible for the conduct of all of the physicists and operators working on the assemblies and he must see that all relevant procedures are rigorously followed by everyone at all times. These include observance of safety procedures for handling radioactive and toxic materials as well as fissionable material. He is assisted in the understanding and formulation of these rules by the hazards control man who is assigned to the critical facility.

4.4.3. Critical Assembly Operators: These people are all personnel assigned to the program other than the project physicist. They may be senior physicists, junior physicists or reactor operators. In all cases, their responsibilities are the same. Under the direction of the project physicist, they carry out the assemblies necessary to complete the experimental program. It is their responsibility to carry out the instrument and safety chain checks, insure that the proper material is being used and make the actual assemblies. They take the data and plot the appropriate inverse multiplication curves. While they are under the direction of the project physicist they are not relieved of any responsibility for the safety of the program. Any operator has complete authority to stop any assembly at any time if he feels that it is or will result in an unsafe configuration. This authority carries with it the responsibility of being thoroughly familiar with all phases of the procedures for the program.

4.4.4. Hazards Control: A member of the hazards control group has his office at the critical facility. It is his responsibility to be aware of the programs which are being carried on in the facility and to assist operating crews to avoid hazards of all types except nuclear hazards. Specifically, the hazards control representative is familiar with the radiological and toxicological problems of handling all types of material. He monitors for radiation in all areas, makes the necessary checks for surface contamination and insures the proper operation of all air monitors. For example, at the present time air monitors are in operation to detect airborne beryllium, airborne alpha activity and fission gases. He assists in the design of hoods and filter systems to prevent airborne activity. He is also familiar with the toxicology of various non radioactive materials such as beryllium and beryllia.

4.4.5. Electrical and Mechanical Maintenance: An electronics shop and a machine shop are located at the critical facility. They are staffed with engineers and technicians who are available at all times to check, repair or replace any equipment which is faulty. The average staff at the facility for these activities is one mechanical engineer, three machinists, four mechanical technicians, two electrical engineers and two electronic maintenance technicians.

V. EXPERIMENTAL PROCEDURES

5.1. BASIC CRITERIA

The most common objective of the experimental programs that have been carried out to date has been the determination of the critical dimensions of the test system. This is by no means the only type of measurement that is made, but is the most frequent type which introduces a criticality hazard. The data on the critical parameters of a system are usually used for normalization of calculational codes used to predict the neutronic behavior of a type of system similar to that measured. These calculational programs are greatly aided when the critical data is obtained from a relatively simple system which introduces as few unnecessary calculational complexities as possible. Such complexities are introduced through inclusion of foreign materials into the system, through the density decrease and neutron streaming introduced by control rod voids, through neutron reflection from the assembly machine and the surrounding walls etc. All critical experiments are designed to reduce such effects to a practicable minimum.

The other primary goal of the design of the experiments is to produce a test system and test procedures which will produce the maximum safety from a prompt critical burst. While the operators are in the assembly room, the system must be sufficiently far sub-critical to prevent a critical condition from being obtained, regardless of the actions of the operators---assuming, of course, that they do not intentionally bring the assembly critical. Normally the operators work on a system manually and reactivity is added by their bodies acting as neutron reflectors, by the addition of fuel, moderator or reflectors or by rearrangement of the system. Shut down reactivities must be sufficient to offset such effects and to offset a reasonable amount of mistakes or errors. During the actual approach to critical, personnel are not in the assembly area. The control and information system must be sufficient to allow the operator to bring the system critical with adequate knowledge of the state of the assembly at any time. It must further contain shut down mechanisms automatically to make the system sub-critical in the event that any one of a certain set of predetermined safety limits are exceeded.

5.1.1. The Control System: The control systems have several design features to allow them to satisfy the criteria given above. These design features appear in the control system used for any specific assembly program, although the manner in which they are met may vary from program to program.

Features incorporated in all control systems are:

a) Safety Chain - A safety chain incorporating all features of the control and safety system is used. The safety chain consists of two parallel chains; each must be complete to avoid a scram (fast shut down). Each safety device operates two relays, one in each of the separate parallel chains. Thus, failure of one relay upon receipt of a scram signal will not prevent a scram.

b) Fail Safe Design - This is used wherever possible. Relays, valves and magnets are kept in the non-scram position by being energized. Any failure or loss of power will allow them to drop into the scram, or safe, position. In many cases, again whenever possible, such failure will trip the safety chain and scram the entire system.

c) Interlocks - These are used for two purposes. In one case they are used to insure that operations occur in the proper sequence. In the other, they are used to prevent unsafe practices, such as entering the assembly area while reactivity increases are possible.

d) Limitation of Maximum Reactivity Increase Rates - Systems of fissionable material must be made safely sub-critical while operators are working on them. This means either the physical disassembly of the system or the insertion of large amounts of negative reactivity through the use of neutron poisons. When the system is then brought to its assembled state, assembly speeds or poison removal rates must be related to the reactivity increase caused by such changes.

For sub-critical systems, the conservative assumption made is that the system must detect a signal corresponding to a scram signal, trip the safety chain and start shut down in a time less than that required to add one dollar of reactivity to the assembly. In this manner, the system should never reach prompt critical during assembly, since the scram levels are always reached before delayed critical is achieved. In practice two assembly speeds are used. The fast speed is used when the system is far sub-critical and a speed is used which adds one dollar of reactivity in the response time of the detector-scram system. Near the final assembly point the assembly speed is reduced so reactivity is added at the rate of one dollar in five to ten system response times. Before the first assembly is made in a program, the reactivity change as a function of the varying parameter can only be estimated. After the first assembly, however, the inverse multiplication curves can be used to give experimental data on the rates and assembly speeds can be adjusted accordingly.

For critical systems, machine calculations are made to investigate the behavior of the system for ramp increases of reactivity of various rates. From such calculations the appropriate safety rod speeds are chosen to assure safe shut down in the event of a malfunction in a rod which causes it to run out at full speed. Since a large amount of shut down is desired, the rod withdrawal pattern is fixed by the interlock chain. In this way speeds for the first rods pulled can be relatively rapid, to bring the system in the range of k between 0.90 and 0.95. Again, as with the sub-critical measurements, the first critical measurements are a determination of rod worths to check the rod speeds. Final safety rod speeds and control rod speeds are always such as to add less than 15 cents per second.

e) Minimum Instrumentation - Due to the fact that experimental programs vary from day to day, the type and number of instruments that are in use at a particular time may vary considerably. The list given below represents the minimum safety equipment which is operating at all times when subcritical assembly operations are underway.

1) Two pulse counters sending signals to two linear count rate meters. These may be fission counters, scintillators, BF_3 proportional counters, etc.
2) One ionization chamber sending a signal to a micro-micro-ammeter.
3) One recorder receiving a signal from one of the above three counters.

If at any time the multiplication of the system results in a counting rate high enough to necessitate the disabling of one or both of the linear count rate meters, additional ionization chambers are used to furnish neutron level information. Each of the counting channels and the recorder will scram the system at a pre-set level. At no time are assemblies made without three independent counting channels giving scram capability and without one recorder having a scram capability operating.

If the system is to be brought to critical, the minimum safety equipment which is kept operating at all times is

1) Two pulse counters sending signals to two linear count rate meters, or;

   Two ionization chambers sending signals to linear micro-micro-ammeters.
2) One ionization chamber sending a signal to a log N and period channel.
3) One recorder receiving a power level signal from one of the above three counters.

Each of the three counting channels must have a scram capability. In addition the period channel must provide a period scram at a 15 second period at all times. The recorder must have a scram capability.

5.1.2. Methods of Increasing Reactivity: The method used to increase the reactivity of a system in order to approach critical is governed by the physics and physical make up of the assembly. In general, however, critical and sub-critical systems can be divided into two general classes. The methods of working with them are quite different in appearance, but both produce the same results; a large amount of negative reactivity during shut down and a controlled addition of reactivity during the approach to critical.

Metal systems, or systems having very lightly moderated cores ("fast" systems) are generally small, relatively light and have relatively few parts. The most practical shut down method is disassembly of the system, usually dividing the core and reflectors into two roughly equal parts. This provides two reactive components, with each no more than half a crit. Adequate safety margins are thus provided for personnel working with the assembly.

Systems having highly moderated cores are generally large, heavy and often contain an exceedingly large number of pieces. Control by the use of nuclear poisons is usually more practical than disassembly because of the inherent difficulty of moving a large mass quickly enough to obtain short shut down times. The negative reactivity introduced at shut down is generally smaller then that obtained by disassembly and a systematic method of checking the shut down reactivity to insure the safety of personnel in the vault is often desirable.

In the sections which follow, a typical system of each type is considered in some detail. The metal system referred to was designed for the Nimbus program. This program was to furnish critical mass data for spherical systems of oralloy in a variety of spherical reflectors. The example used to illustrate the moderated core systems is the Snoopy experiments. These experiments were done to determine the critical parameters of systems composed of graphite plates and oralloy foils, with a variety of carbon to uranium ratios.

5.2. A MODERATED CORE EXPERIMENT - SNOOPY

The majority of the information given in this section is taken from declassified documents dealing with the Snoopy program. In particular, reference is made to COVA 346, Snoopy Libretto, and UCRL 5006, Critical Measurements on Intermediate Energy Graphite - U^{235} Systems. Material from these documents is quoted at length in the sections below. Reminder is made at this point that this material is included only to illustrate the type of considerations that are routinely made at the LRL Critical Facility for every critical assembly program. This work was performed during the period 1957 - 1958. The Snoopy machine is still in use for other experiments of a similar nature, but numerous modifications have been made in the past two years.

5.2.1. Programmatic Objectives: The Snoopy program was designed to furnish the critical bucklings of a large number of bare carbon - enriched uranium reactors. These reactors were designed to approximate as closely as possible an elementary neutronic system, i.e. a homogeneous, unreflected cubical reactor containing only carbon and uranium with no voids or holes. A number of compromises dictated by reality were necessary, as described in the sections below.

5.2.2. Materials: A selection of nominally 1- and 2-mil-thick oralloy foils in 5-1/4" x 5-1/4" squares and isosceles triangles was used for fuel. All foils were coated with a fluoro carbon plastic to prevent oxidation and to reduce erosion. These fuel foils had a normal average surface reading of 3/4 mr/hr gamma and 10 mr/hr beta radiation.

The moderator was ATJ graphite machined in 1/2" thick, 6" x 6" squares and triangles. A 10-mil recess was milled in the top of each piece to accommodate the fuel foils. A core lattice of one 2-mil fuel foil on top of each graphite plate gave a nominal atomic carbon to U^{235} ratio of 600/1.

5.2.3. The Assembly Machine: The reactors were assembed on a low mass stacking table around a central control unit. The table consists of an 8' x 8' x 1' aluminum honeycomb slab, rigidly supported by an aluminum stand. The honeycomb is made of 2-mil 2S aluminum foil in a 3/8" hexagonal cell lattice with a density of 3 lb/ft^3. The top of the table is four feet from the floor to reduce neutron reflection from the floor.

The control unit is suspended from a braced post-and-beam aluminum frame. The control unit is a 2S aluminum cannister with four channels in X-cross section (each 1/2" x 6" exterior dimensions) mounted beneath the drive assembly. Each channel guides a 1/4"-thick, 4' long boral rod. Three of the elements are five inches wide and serve as safety rods. The fourth is one inch wide and serves as a control rod. A tube through the cannister axis permits the insertion of various sources into the core.

The three safety rods are lifted by electromagnets suspended by cables from the top of the unit. The rods drop when the magnets are de-energized following a scram signal. Shock absorbers minimize bouncing of the scrammed elements. All three safety rods are raised by electric motors which wind the magnet support cables on drums.

The control rod is moved by an electrically driven jack screw which provides rates of 1 inch/minute and 10 inches/minute for both insertion and withdrawal. This rod runs in on receipt of a scram signal.

Two polonium berylluim sources are used. Source No. 1 had a strength of about 10^7 neutrons/second and is manually operated from the control room by a pulley system. It is used to take base rates and to drive the system at low multiplications. During core loading operations this source is withdrawn to a position on top of the timbers of the vault. This position is indicated by a control panel light.

Source No. 2 has a strength of about 10^5 neutrons/second and is electrically operated by a mechanism beneath the core which pushes it out of the top of the core. The interlock and safety chain assures that this source is in the reactor at all times when personnel are in the vault or when safety and control rods are being withdrawn. It is necessary to remove this source only to make a positive check for criticality or to make flux traverses in the reactor.

A paraffin slab will be used to simulate the reactivity change through neutron reflection introduced by operators working on or near the core during core alterations. By extrapolating a series of measurements, to be described in section 5.2.7., the operators can know if a contemplated manual increase in core loading can be done safely.

The paraffin slab is four feet high, two feet wide and eight inches thick, and it is mounted with the four foot by two foot surface parallel to one face of the core. An electrically driven carriage mounted on rails is used to transport the slab from the east vault wall to a position near the core surface. The extreme positions are indicated by control panel lights. The carriage is operated from the control room and is in the safety chain in such a manner that it cannot be used as a reactor control. A manually inserted locking pin mechanically locks the slab carriage in the fully retracted position. This prevents any accidental closure of the slab to the core during core loading operations.

5.2.4. Instrumentation

At low multiplications the assembly will be driven by a 10^7 n/sec Po Be source. Since power levels of less than one watt are contemplated for irradiation studies, there will be 10^{10} fissions/sec occurring in the core during irradiations. To be on the safe side a range of about 10^4 must be covered by the detectors. A number of different types of detectors are used to give adequate coverage over this range.

Two types of neutron detectors are used for the lowest flux levels: LiI (Eu) scintillation detectors and a Hansen-McKibben long counter, each with an amplified scaler and count rate meter. The scintillation detector-count rate meters are sensitive down to approximately 10 n/cm^2/sec and have a 4 decade range. The Hansen counter covers the range of 10-10^4 n/cm^2/sec.

Two Beckman micro-microammeters are employed. Each has a six decade range and a time constant varying between 0.12 seconds and 1 second, depending on the range. A BF_3 ionization chamber is used with Beckman meter No. 1, and covers a range from 10^2 - 10^8 n/cm^2/sec.

For higher levels a boron lined ionization chamber drives Beckman meter No. 2 to cover a range from 10^4 - 10^{10} n/cm^2/sec.

Another BF_3 ionization chamber operates a log n amplifier, reactor period meter (response time 1/2 sec above 10^3 n/cm^2/sec) and recording potentiometer. This logarithmic monitor covers the range from 10^2 to 10^7 n/cm^2/sec.

All of these neutron detectors are in the safety chain, hence a high flux level will scram both the linear and log n detectors; a fast reactor period will scram the log n period meter. By providing six independent neutron flux monitors and a reactor period meter, the feasibility of an electronic failure affecting the safety of the assembly is greatly reduced. A block diagram of the instrumentation is shown in Figure 5-1.

A remote recording area survey monitor is also installed in the experimental facility to monitor γ flux levels during and after operation. The instrument has three monitoring stations in the vault and has a range of 1 mr/hour to 1000 R/hour.

5.2.5. Interlocks and Safety Chains

Reactivity for a given core can be changed by the three electrically driven safety rods and one electrically driven control rod, any self propelled body reflector and a paraffin slab reflector. Obviously an interlock system is needed to reduce the risk of accident from either personnel or equipment failure.

Scrams

Two separate scram circuits (i.e., safety chains) are provided (see Figure 5-2).

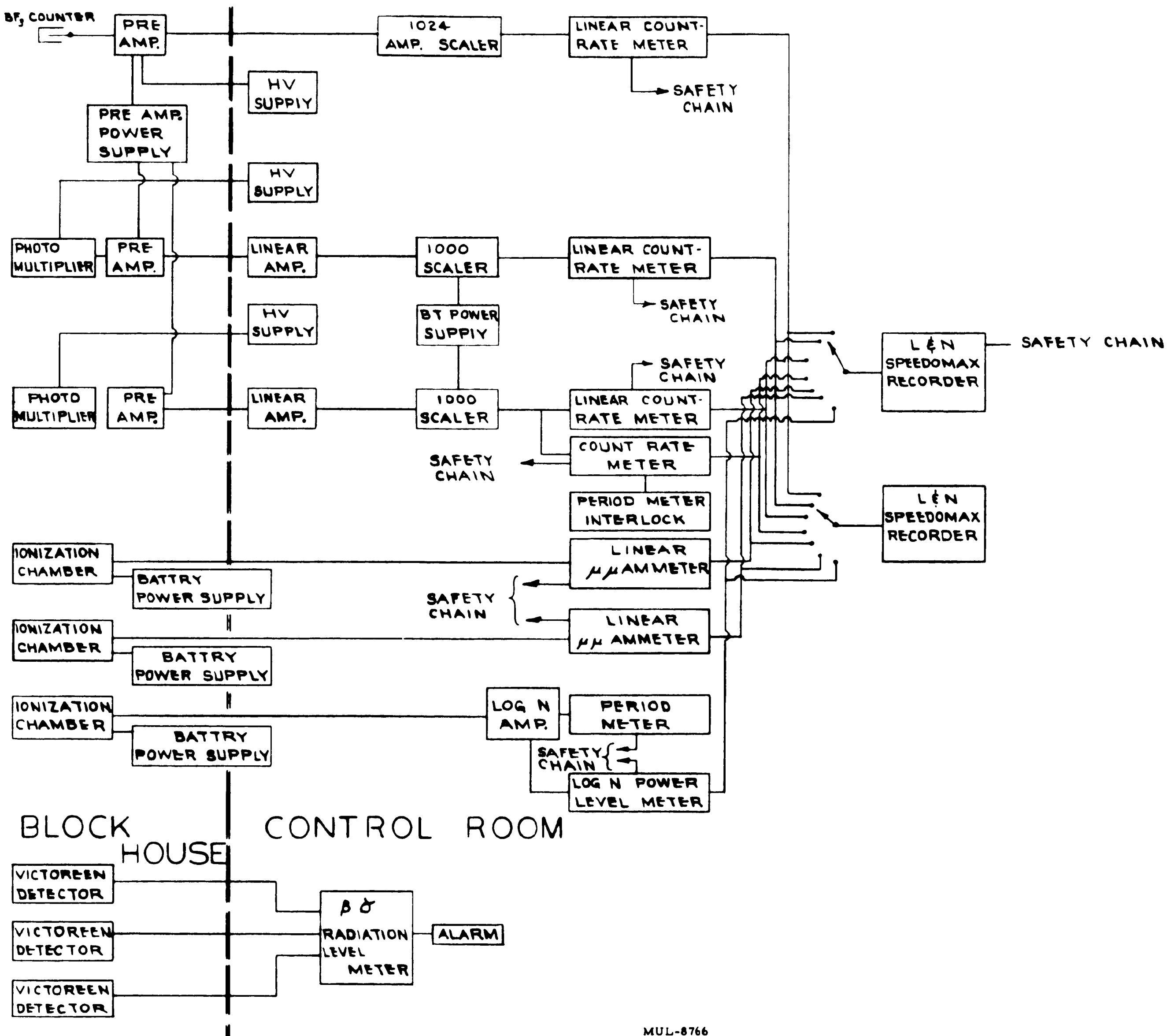
1. Safety Chain No. 1

   Microswitches and multiple contact relays are wired in series for Safety Chain No. 1 so that this circuit will be broken by any one or more of the following items:

   (a) Neutron flux exceeds predetermined level as indicated by:

      (1) CRM No. 1 with input from a Hansen-McKibbin long counter.

      (2) CRM No. 2 with input from PM No. 1 -- a LiI (Eu) scintillation detector.



SNOOPY NUCLEAR INSTRUMENTATION

FIGURE 5-1

(3) CRM No. 3 with input from PM No. 2 -- a LiI (Eu) scintillation detector with boron filter.

(4) Log CRM with input from PM No. 2

(5) Pile power with input from BF_3 ionization chamber No. 1 log scale.

(6) Beckman micro-microammeter No. 1 and recorder with input from BF_3 ionization chamber No. 2.

(7) Beckman micro-microammeter No. 2 with input from a boron lined ionization chamber.

(b) Pile period faster than predetermined level as indicated by:

(1) Pile period meter with input from BF_3 ionization chamber No. 1.

(c) Over-under voltage switch

(d) Seismic switch

(e) Control room manual scram

(f) Control panel key switch

(g) Maze door (chain breaks when door is opened)

(h) Vault door safety switch (manual control)

(i) Two vault safety switches (manual control)

(j) Water door interlock

(k) Paraffin slab (chain breaks when slab leaves wall)

(l) Safety rod pins (chain breaks if safety rods are secured to magnets by manual pins)

The following controls are scrammed whenever Safety Chain No. 1 is broken:

(a) Safety Rod No. 1

(b) Safety Rod No. 3

(c) Control Rod No. 1 (electrical)

The circuitry is arranged so that the following sequence occurs after Safety Chain No. 1 scrams:

(a) The Control Rod is driven at fast speed to the fully inserted position;

(b) The carriages for Safety Rods No. 1 and No. 3 unwind at fast speed toward the full down position;

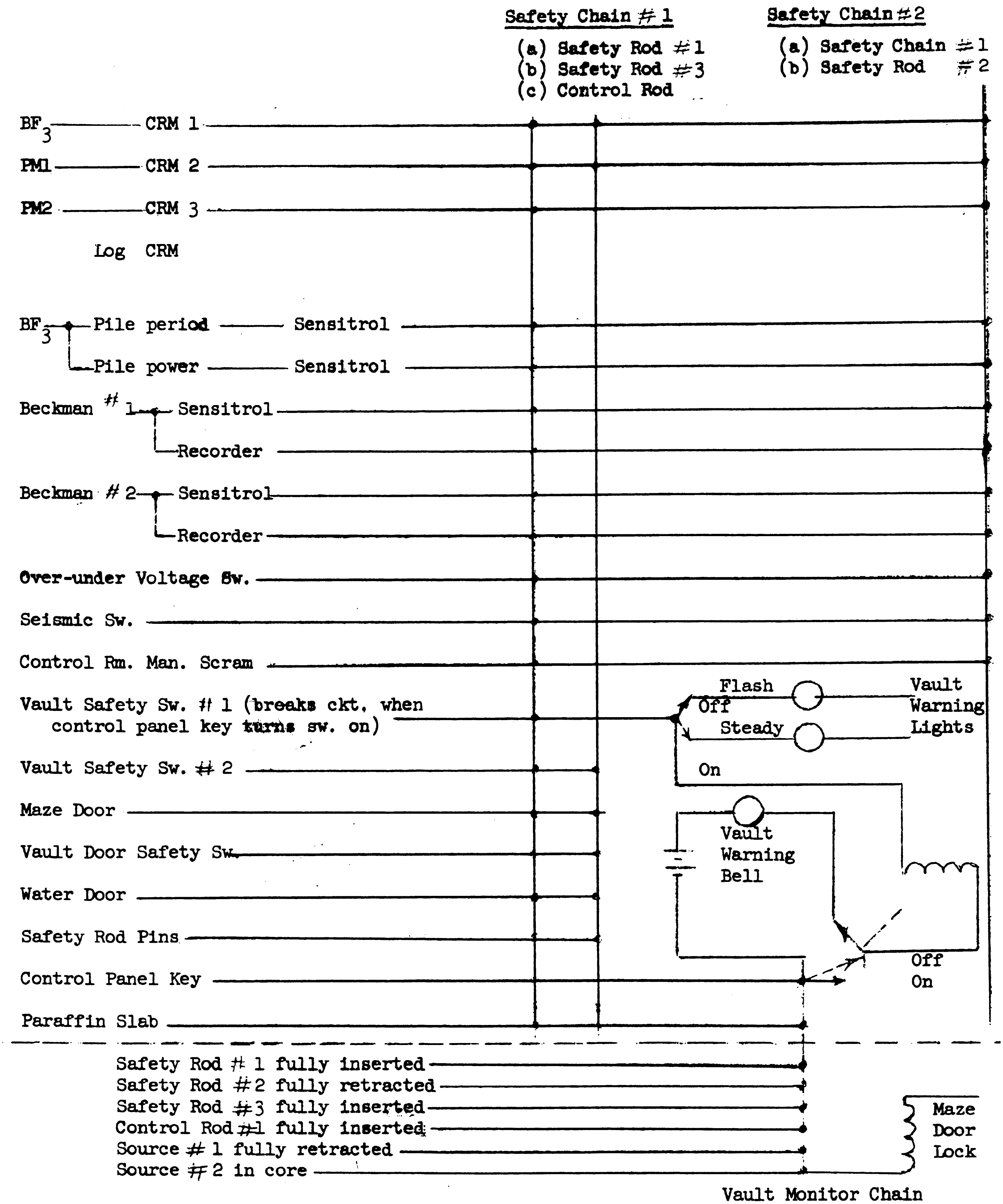


FIGURE 5-2

SNOOPY INTERLOCK AND SAFETY CHAINS

(c) The suspending magnet for Safety Rod No. 1 can not seal until the carriage for Safety Rod No. 3 is in the full down position.

2. Safety Chain No. 2

This chain serves two important functions: it backs up Safety Chain No. 1; it provides a protective monitor when the vault is occupied. Its series circuit is comprised of all elements in items "a" through "e" of Safety Chain No. 1.

The following items are scrammed whenever Safety Chain No. 2 is broken:

(a) Safety Chain No. 1

(b) Safety Rod No. 2

<u>Vault Monitor System</u>

Safety Chain No. 2 provides a protective monitor while the vault is occupied for core alterations or stacking, and will scram Safety Rod No. 2 should a dangerous situation be approached.

The vault is considéred safe for restricted occupancy whenever all of the following items in the monitor chain are accomplished:

1. Safety Chain No. 1 is scrammed;
2. Safety Rod No. 2 is fully raised;
3. Source No. 1 is fully extracted to a position above the ceiling timbers;
4. Source No. 2 is in place in the core;
5. The paraffin slab is fully retracted.

A solenoid lock on the maze door is wired to prevent entrance to the vault unless this monitor chain is made up. In addition, a warning feature consisting of a bell and a light is installed in the vault and is set in operation whenever the control panel key switch is turned off. A safe occupancy condition is indicated by the light on and the bell off; the light turns off and the bell rings to indicate an unsafe condition whenever the warning chain is broken. Thus the system is fail safe. For the "safe" condition with light on, the light burns steadily when the vault safety switch is actuated with the control panel key, but flashes when the key is removed.

Safety Rods

The three safety rods are separately suspended in the retracted position above the core by individual electromagnets. They are scrammed by deenergizing the magnets. Safety rod No. 2 is normally out of the core to provide protection for personnel who are working on the core. No safety rod can be withdrawn unless:

1. The control rod is fully inserted.
2. Source No. 2 is in the core.
3. The paraffin slab is fully retracted.

Interlocks require that rod No. 1 be fully withdrawn before rod No. 3 can be withdrawn, and that rod No. 3 be fully withdrawn before the control rod can be moved. Only one rod can be withdrawn at any time under any conditions.

Rod drop experiments have shown that shutdown is accomplished within 0.4 seconds after scram initiation. The experimental result is consistent with expected rod free fall times and magnet release times. The scram signal for such tests was generated by a level scram on a neutron detector so the shutdown time includes the level indicator response time.

Far subcritical, reactivity may be safely removed more quickly than when near critical. The safety rods therefore have different removal speeds and interlocks govern the sequence of rod removal, the fastest being withdrawn first. Typical withdrawal speeds are 300 inches/minute for safety rods 1 and 2, 10 inches/minute for rod 3 and 10 inches/minute for the control rod. These speeds are adjustable and they are chosen with regard to the worth of rod and the system reactivity when they are pulled.

Control Rod

The control rod is positioned in the core by a two-speed electrical drive and can not be withdrawn unless:

1. All safety rods are fully withdrawn.
2. Source No. 2 is in the core.
3. The paraffin slab is fully retracted.

Sources

An interlock is provided so that the following operations are impossible unless Source No. 2 is in place in the core:

1. Withdraw Safety Rods No. 1 and No. 3.
2. Withdraw the Control Rod.

If either the Safety Rods or the Control Rod is in the process of withdrawal and Source No. 2 is removed from the core, the respective rod will stop. However, an operator can still run the Control Rod back into the core (or the Safety Rods if the Control Rod is fully inserted) even with the source removed.

An interlock is provided so that unless Source No. 1 is nested in its fully retracted position above the ceiling timbers, and unless Source No. 2 is properly positioned in the core:

1. The maze door can not be opened;
2. An alarm bell in the vault monitor system will ring when the control panel switch is turned off.

Paraffin Slab

The slab is microswitched against the wall so that the following things occur whenever the slab leaves its fully retracted position:

1. Safety Chain No. 1 scrams.
2. Maze door will not open.
3. Vault warning system signals an unsafe condition (whenever the control panel key switch is turned off).

A manual locking pin is provided so that the slab can be locked against the wall when the vault is occupied. Insertion of the pin operates a microswitch which breaks the slab electric drive circuit. Power to the slab electric drive is also interrupted by turning off the control panel switch. Thus the paraffin slab can not be electrically operated from the control room unless:

1. The control panel switch is on.
2. The slab manual locking pin is removed.

5.2.6. Operating Characteristics

Several sources of potential nuclear accidents are associated with the type of critical assembly to be pursued in the Snoopy program.

A fundamental safety criterion is to limit the total available reactivity in the assembly so that prompt criticality is impossible. Thus, it is necessary to know how much an additional 1/2" layer of core is worth near criticality so that the core height can be increased in increments of less than 0.7% reactivity at a time as the critical condition is approached. In a later paragraph it is shown that at criticality a 1/2" additional core layer introduces less than 0.4% reactivity for a typical system.

The Snoopy reactor studies do not require very much potential excess criticality. It must be possible, however, to vary the reactivity by small amounts for reactor control. A single control rod is used in Snoopy with the intent that the assembly remain sub-critical on this rod alone when fully inserted. This means that the total rod worth must be between 0.5% and 1.0% in reactivity.

It is fortuitous that control requirements match the safety requirements of limiting dk/dt for the control rod. But, since the control rod is allotted only a small influence on the core reactivity, the preceding element which is withdrawn from the core must be carefully examined for proper time behavior. This is Safety Rod No. 3 in the Snoopy design. It is electrically operated and interlocks govern the sequence of rod operation to assure that the proper elements are used in the proper order.

Another complication for unreflected Snoopy cores is body reflection. In this phenomena the core reactivity is increased through moderation and reflection of neutrons by the bodies of operators when adjustments are made on the shut down core. An additional safety rod (No. 1) is used to counter body reflection and also as insurance when a scram occurs.

Until the actual worth of the control elements is experimentally evaluated, their effectiveness is, in truth, only an educated guess. For this reason a paraffin slab is provided to mock up an operator's body reflection so that a sequence of measurements may be extrapolated to show if a contemplated manual increase in core height is safe.

As an additional precaution, one more safety rod (No. 2) is provided for Snoopy. This rod will be used only for scrams. During core stacking operations (or at any time the vault is occupied) it is suspended above the core, ready to drop in the event of a developing dangerous situation as sensed by an associated monitoring system.

Finally, no critical assembly is undertaken without an adequate source of neutrons available for continuous triggering of the fission process. Two neutron sources are provided in the Snoopy design, and interlocks assure that at least one source must be properly nested in the core before core adjustments are made.

Reactivity Changes

A series of calculations were made using the Dane code on systems having linear increases of reactivity. These systems were assumed to have prompt neutron generation times of 10^{-4} seconds which is reasonable for these systems. An energy release was calculated for the interval from scram signal initiation to full safety rod insertion. The calculations of energy release are an over estimate because power was assumed to rise, unaffected by the safety rods until full insertion was achieved. One second was assumed to be required for scram shut down. This is also pessimistic, because rod drop measurements have shown that shut down is accomplished 0.4 seconds after scram initiation. A tabulation of the results of the calculations is given below. In each case the initial power level at the start of the ramp increase was assumed to be 10^8 fissions per second.

ℓ*	dk/dt	Power Scram	Period Scram	Power At Scram	Period At Scram	Time Before Prompt Critical	Energy Release
10^{-4} sec	.05%/sec	1.5 watt	- - -	1.5 watt	1.4 sec	5 sec	4.6 watt-sec
" "	" "	- - -	5 sec	.13 "	5 "	10 "	.39 " "
" "	0.1%/sec	1.5 watt	- - -	1.5 "	0.6 "	1.6"	12 " "
" "	" "	- - -	5 sec	.11 "	5 "	5 "	.4 " "

These results show that shut down following a ramp increase of reactivity would be accomplished with a satisfactory margin of safety if the following criteria were met:

1. Maximum rod dk/dt $\leq$ 0.1% reactivity/second.
2. Scram signals set for
   (a) Less than 1.5 watts power level
   (b) Greater than a positive 5 second period
3. Scram interval less than one second.

The reactivity worth of the control system has been checked during the course of an experiment by inverse multiplication curves such as those as shown in Figure 5-3. The rod effects in terms of inches in system height are obtained in this way, and this provides sufficient information to allow the tests to be conducted safely. For example, in the case shown in Figure 5-3, the system height could be made 41 inches with the assurance that body reflection by one operator would not make the system critical unless all three safety rods were out of the system. Or, with the Control Rod and Safety Rods 1 and 3 inserted, the core could be stacked to 44 inches without making the system critical in the presence of the operator. This would be a stacking error of three inches beyond critical with rods out, and is hardly a credible error.

The core height changes have been correlated with reactivity changes by the use of pulsed neutron source methods. For the system shown, one inch in height corresponds to \$1.38 and the total shut down reactivity is about \$7.00. The worth of Safety Rod No. 3 is seen to be 2.3 inches in height, or about 2.3%. The withdrawal speed is 10 inches/minute and the average rate of reactivity increase for this rod is less than 0.01%/second. The maximum rate is then certainly less than 0.03%/second, which is well below the rates which gave safe situations when used in the Dane code calculations.

The control rod worth, for the situation shown in Figure 5-3 is 0.7 inches in height, or about 0.7% in reactivity. The average reactivity increase rates are then less than 0.003%/second for the fast speed of 10 inches/minute and less than 0.0003%/second for the slow speed of 1 inch/minute.

SUMMARY OF DATA FROM ONE DETECTOR FOR
VARIOUS ROD CONFIGURATIONS

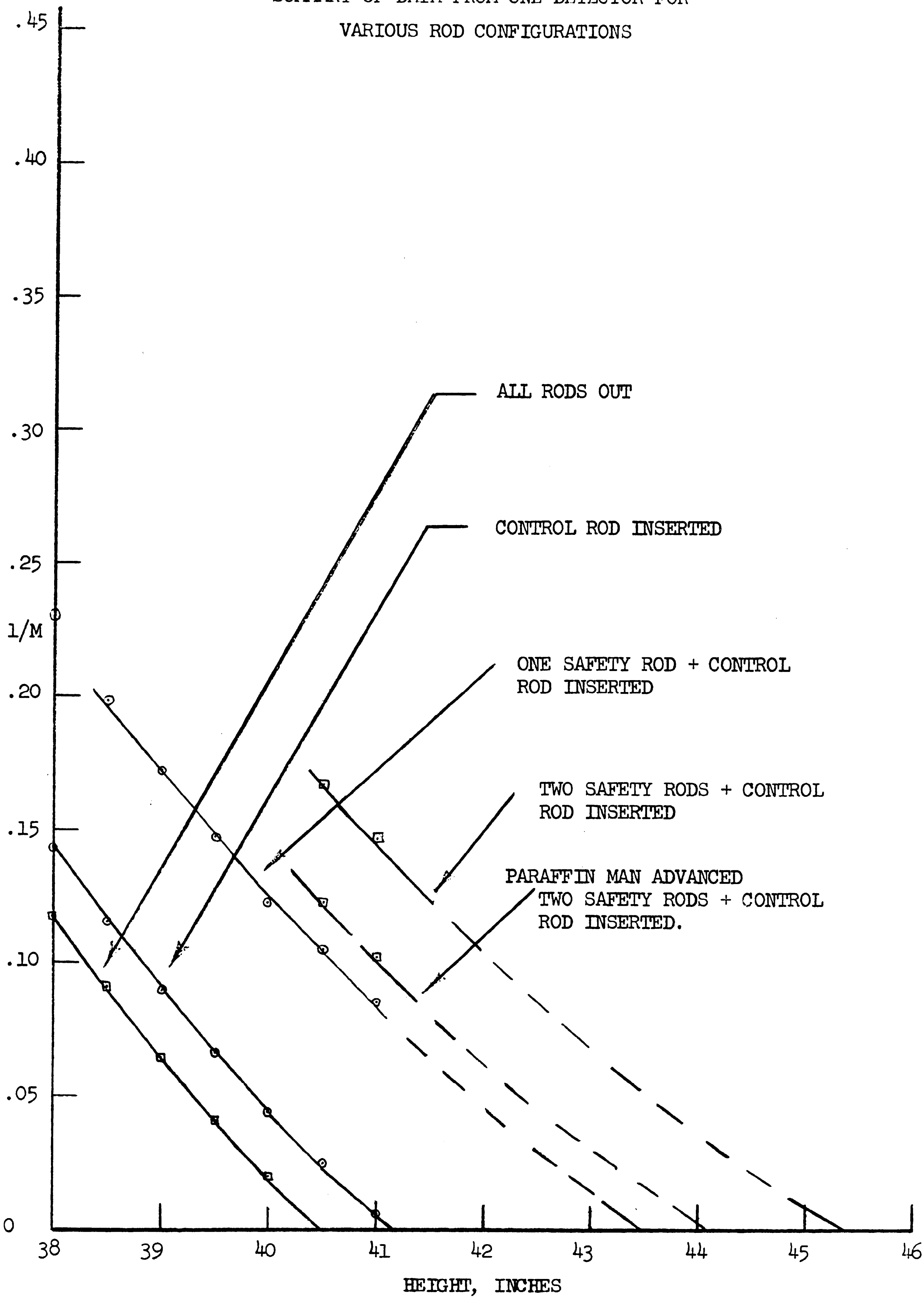


FIGURE 5-3

5.2.7. Operational Procedures for Snoopy Experiments

The procedures used by the operations crew are fully outlined in the assembly procedure for the experiment. The use of these procedures has been described in section 4.3. The assembly procedure for the Snoopy work is included in its entirety in Appendix C.

5.3. AN UNMODERATED METAL CORE EXPERIMENT - NIMBUS

The majority of information in this section is taken from declassified documents dealing with the Nimbus program. In particular, reference is made to UCRL 4975 "Critical Masses of Spherical Systems of Oralloy Reflected in Beryllium". Again, this material is included to serve only as an example of the manner in which fast system assemblies are made at the LRL Critical Facility. This work was performed during 1958 - 1959. The Nimbus machine has subsequently been dismantled and removed from the West vault.

5.3.1. Programmatic Objectives

The Nimbus program was designed to furnish data on the critical mass of oralloy in spherical geometry, as a function of reflector thickness for various reflectors. The experimental systems were designed to be as nearly an ideal system as possible. They were to be spherical, have no extraneous materials in the core or reflector, have no voids in the core or reflector and have no neutron reflection from the assembly machine or the vault. As is always the case, some compromises with reality had to be made.

In order to supply the desired information it was not necessary to construct exactly critical systems. Adequate determinations of the critical deminsions could be made by sub-critical, inverse multiplication measurements. Hence, no equipment or instrumentation, such as control rods and period meters, commonly used in critical systems was provided.

5.3.2. Materials

The fissionable material used for the core consisted of a set of nesting hemispherical oralloy shells and an oralloy sphere. The sphere had a diameter of 2.477 inches. The shells ranged in wall thickness from 0.090 inches to 0.175 inches. A total of twelve core diameters ranging from 2.477 inches to 7.196 inches could be achieved.

The sphere was drilled to receive a 0.410 inch diameter polonium beryllium neutron source, with an oralloy plug to fill the remainder of the source hole. All assemblies were therefore made with a central 0.410 inch diameter central hole, which was essentially filled with beryllium.

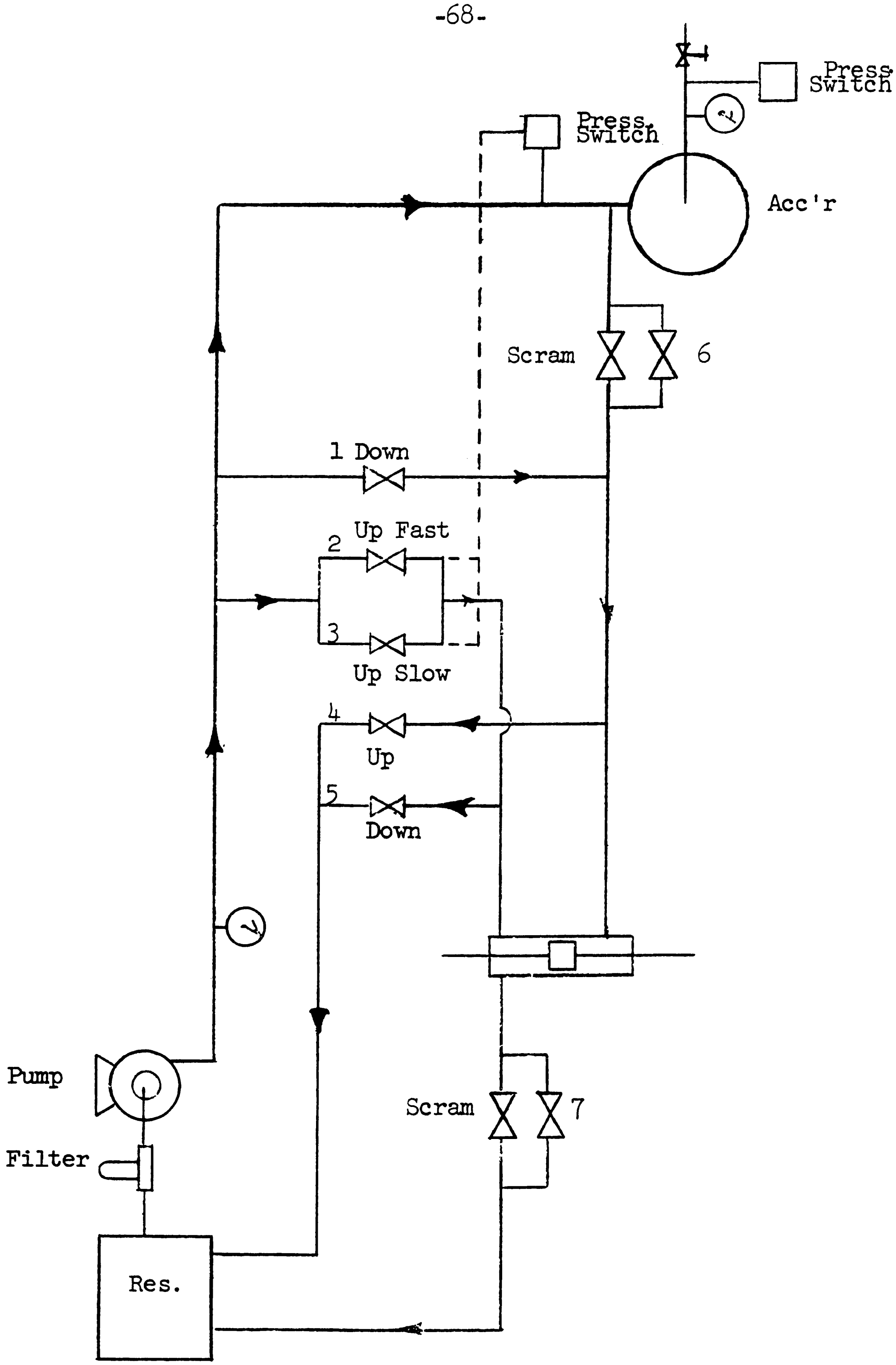
The reflector used was beryllium. It also consisted of a set of nesting hemispherical shell, with a maximum diameter of 22 inches. Below 7.916 inches in diameter the beryllium shells were identical in diameter and wall thickness to the oralloy core shells. In this way, every core size could be fitted with a beryllium reflector of various thicknesses.

5.3.3. The Assembly Machine

The assembly machine is basically an hydraulic jack with an 18 inch stroke. Assemblies are made by suspending the upper half of the reflector and a portion of the core by a quarter inch stainless steel rod, positioning the remainder of the assembly on the ram and raising the ram until the two parts of the assembly are together.

The ram itself is a double acting piston within an 18 inch long cylinder. The piston is 36 inches long so that it is always supported at both ends, to prevent wobbling of the assembly at the end of the stroke. When the piston is down, 18 inches of the piston project below the cylinder into a hole in the floor. The effective area of the piston is 3.9 square inches and the hydraulic system pressure is 300 pounds/square inch. Two ram speeds are provided by having parallel up valves (valves 2 and 3) only one of which is open at a time. Orifices in the valves are adjusted to provide the flow of oil necessary to give the desired speed.

The hydraulic system is shown in Figure 5-4. Scram capability is provided by valves 6 and 7 which open on a scram signal. These valves are normally open and scram the system when holding power is lost. All other valves are normally closed valves. The accumulator is in the system to provide a source of stored power in the event of a power failure when the pump would be lost. It also can force fluid into the top of the cylinder more rapidly than can the



HYDRAULIC SYSTEM FOR THE NIMBUS ASSEMBLY MACHINE

FIGURE 5-4

pump. Thus, if on receipt of a scram signal valve 2 failed to close as it should, the accumulator pressure would override the pump pressure which would be relieved through valve 7, the piston would thus be forced down. The accumulator has a pressure switch which prevents completion of the safety chain until pressure in the accumulator reaches 300 pounds/square inch.

Normal valve positions are:

Valve	Up Motion	Down Motion	Scram
1	Closed	Open	Closed
2	Open (fast)	Closed	Closed
3	Open (slow)	Closed	Closed
4	Open	Closed	Closed
5	Closed	Open	Closed
6	Closed	Closed	Open
7	Closed	Closed	Open

A set of remotely operated aluminum spacers is provided on the machine to insure that the assembly does not close beyond the point desired. These spacers consist of three sets of fingers spaced at 120° around the core. Each set of spacers has a total thickness of one inch. When the control button is pushed, the top spacer of each of the three sets rotates out of the way allowing the assembly to close to the new separation. In this way closure steps of 1.000, 0.700, 0.450, 0.250, 0.175, 0.100, 0.050 and 0 inches are positively established. It is not possible for any malfunction of the machine to force a closer gap than that established by the spacers. If, for example, the operator keeps the up button depressed, the upper half of the assembly will be lifted on the spacers until the end of the ram stroke is reached. The various features of the machine can be seen in Figure 5-5 which shows an assembly partially completed. The ram is almost fully extended, and the spacer system is between the two halves of the assembly.

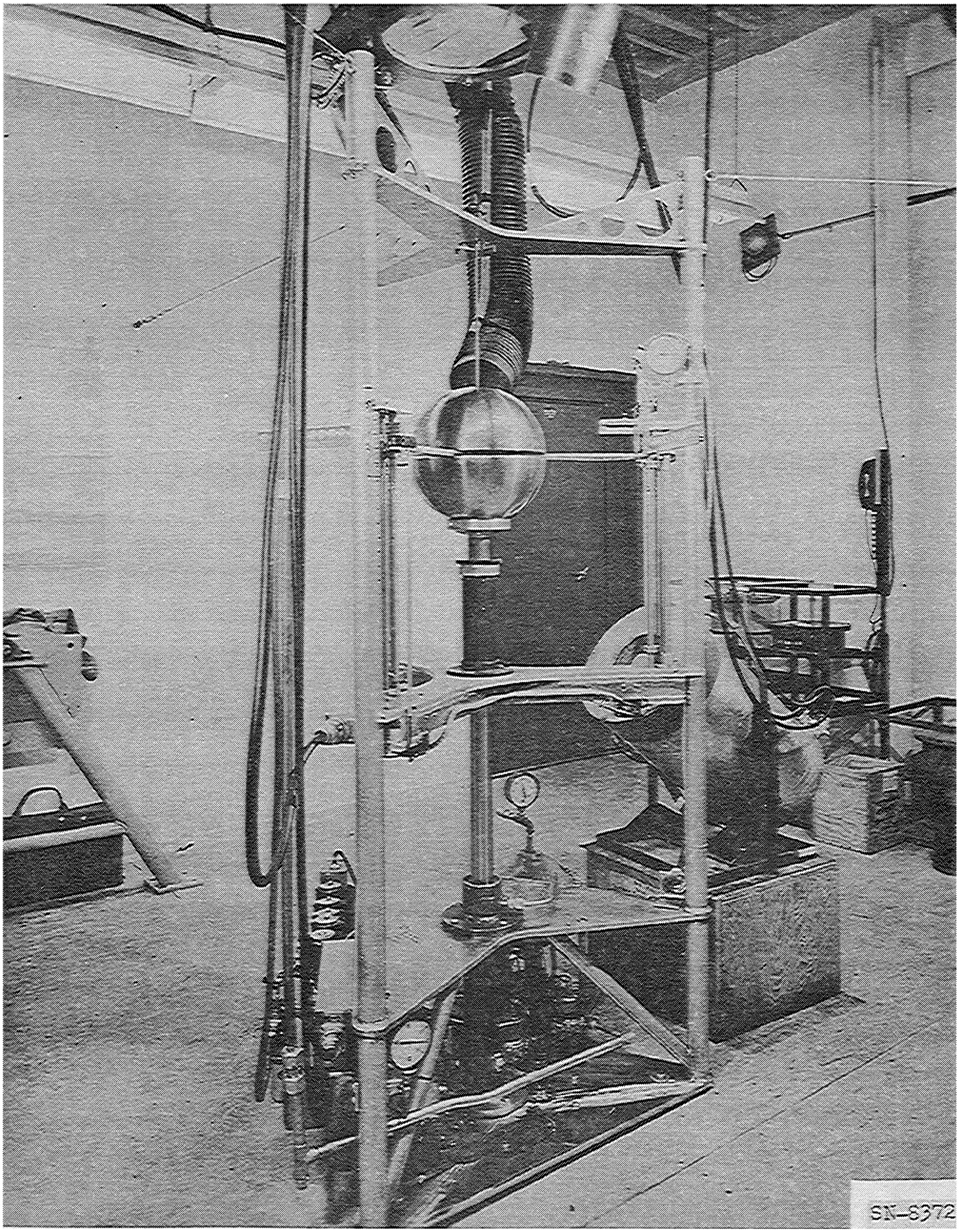


FIGURE 5-5

The upper half of the assembly is suspended on a quarter inch diameter stainless steel rod, and its lower surface is always in the same position, since addition of shells is always made to the outside. The lower half of the assembly is bolted to an adjustable height support on the ram. As shells are added to the lower half, the upper surface is raised. This is compensated for by lowering the adjustable support.

A switch which contacts the upper surface of the lower half of the assembly disables the fast speed of the ram. The operator must then switch to slow speed to bring the two halves closer than one half inch.

5.3.4. Instrumentation

The assemblies are driven by a polonium beryllium neutron source having an emission of approximately 10^6 neutrons/second. Since multiplications of 100 are not exceeded during the measurements, a range of only 100 needs to be covered by the detectors. This makes it possible to use linear amplifiers and count rate meters throughout.

Three paraffin moderated and collimated BF_3 tubes are used for the primary neutron detecting instruments. Each of the BF_3 proportional counters sends a signal to a linear amplifier and then to a scaler. The scaler output feeds a linear count rate meter. Each of these count rate meters generates a scram signal if a predetermined level is exceeded. The scram level is easily adjusted by controls on the front of the chassis. Since these are linear meters with two scales per decade, it is necessary to switch scales several times during one assembly sequence.

One BF_3 filled ionization chamber sends a signal to a linear micro-microammeter. This instrument does not customarily show a usable signal at the low neutron level common to multiplication measurement (0.01 to 0.1 watts total power at the highest multiplications) but it provides a non-saturating detector which would not block upon receipt of a sudden, very large number of neutrons. It is therefore used to insure a scram signal to provide an ultimate scram to prevent repetitive pulsing or prolonged operation at a high power following a prompt burst.

A Speedomax recorder can be switched to the output of any of the count rate meters. It is also provided with an adjustable scram setting and is part of the safety chain.

A recording radiation area monitor is installed in control room with two gamma sensitive stations in the vault. This is a Victoreen system, with a range of 1 mr/hour to 1000 R/hour. Each station has an alarm which sounds in the control room and in the vault when a pre-set radiation level is exceeded. During operation, the level in the vault is dependent on the type of the assembly, the driving source and the multiplication. While work is being done in the vault, these systems are meant to furnish a guide to the operators and to serve as a warning in the event of any unexpectedly high levels which might occur during manipulation of the assembly by the operators.

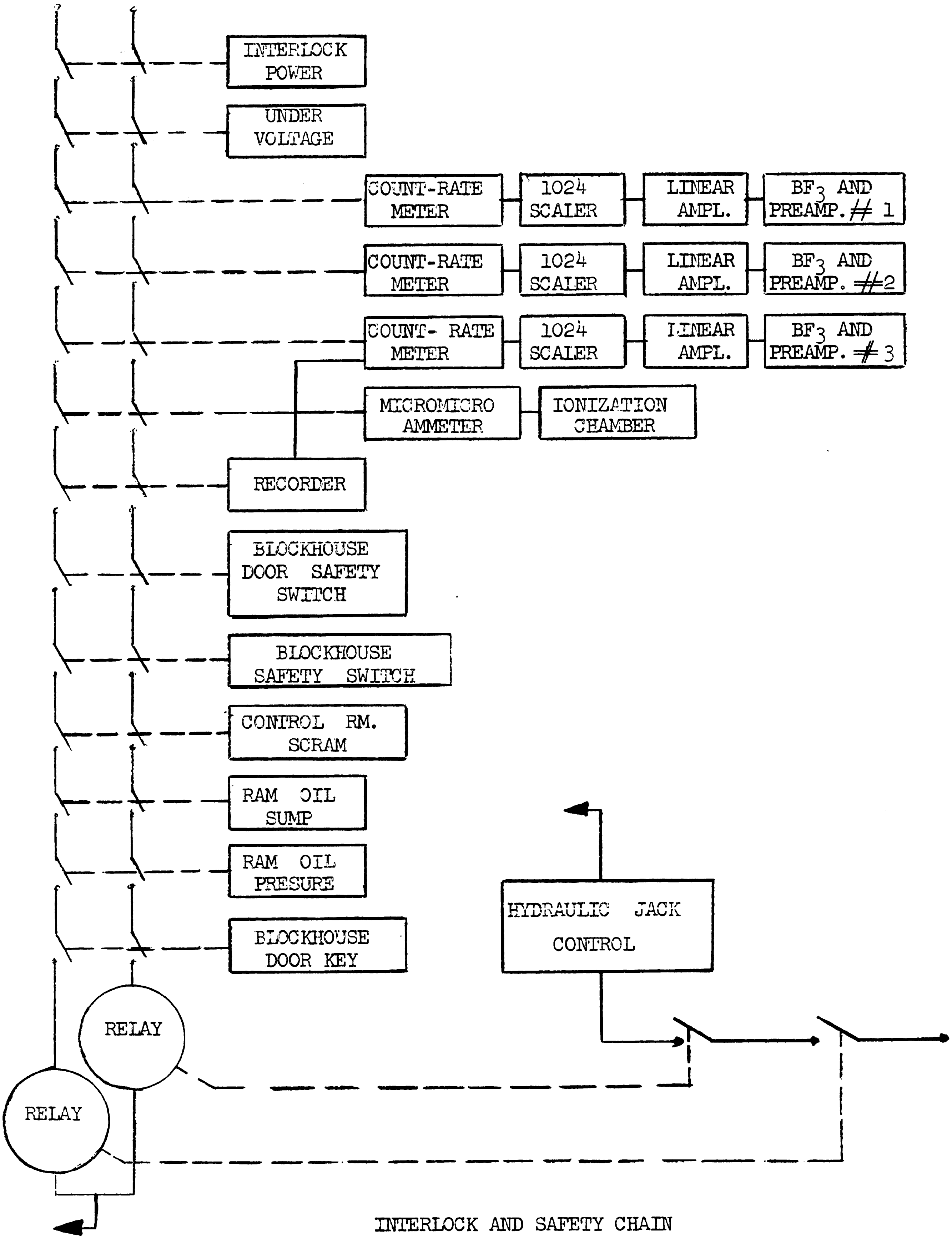
5.3.5. Interlocks and Safety Chains

When the assembly machine has separated the system in two parts, each part is presumably safe for any operations which the operator might do consistent with the assembly procedure. This is one of the fundamental purposes of the assembly procedure. Therefore, the interlocks and safety chain have as one of their primary purposes the guarantee that the device will be disassembled whenever personnel are in the vault. The other purpose of the safety instrumentation is to stop the assembly whenever any predetermined safety limits are passed. The instrumentation block diagram and safety chains for the Nimbus system is shown in Figure 5-6.

Interlocks

The first purpose of the system is insured by providing that the machine scrams for the following cases:

1. Control console key is removed (this key is required to open the maze personnel door).
2. Personnel door open.
3. Any one of three manual safety switches is thrown.



INTERLOCK AND SAFETY CHAIN

FIGURE 5-6

Scrams

The second purpose of the system is insured by causing a scram signal for any of the following events:

1. Neutron flux exceeds a predetermined level as shown by:
   (a) CRM 1
   (b) CRM 2
   (c) CRM 3
   (d) μμa
   (e) Recorder
2. Incoming line voltage too high or too low.
3. Seismic signal.
4. Control room manual scram.

5.3.6. Operating Characteristics

In a multiplication experiment, which is essentially an approach to critical where the reactivity of the system is never supposed to exceed 99% of delayed critical, it is usual to start with an amount of material known to be sub-critical and to vary some parameter in discrete steps until the maximum desired multiplication is achieved. A multiplication measurement is made at each step, and the inverse of this multiplication is plotted as a function of the parameter being varied. In this way, by extrapolation, the reactivity of the next step can be estimated. The shape of an inverse multiplication curve can be concave, convex, S shaped or a straight line, depending on the parameter vaired, the source position, detector position etc. Consequently, extrapolations of the curves must be made over very limited ranges. An inverse multiplication curve for a Nimbus system is shown in Figure 5-7 where the inverse multiplication is plotted as a function of the separation of the two halves of the assembly. For this particular case the system would have been delayed critical at a separation of about 0.020 inches. Since it is the primary datum from which the operator predicts the behavior of the system for an increase in reactivity, the inverse multiplication curve is included as part of the operating system. There is little in general that can be said regarding their characteristics other than that they should be prepared with care and accuracy and interpreted conservatively and warily.

A small metal system, separated by a distance at least as great as its largest linear dimension is far sub-critical. Or, it could be said that the system has a large amount of negative reactivity which must be removed. This is done with the assembly machine, at assembly speeds which must allow the safety instrumentation to detect a dangerous power level, respond and disassemble the system before a prompt critical condition can be reached, with an adequate safety margin, as discussed in section 5.1.1.

The scram mechanism is a powered downward motion of the ram, where the power is supplied by the stored air in the accumulator. Measurements have shown that the ram begins its downward motion with an initial acceleration of 1/3 g starting 0.075 seconds after a scram signal is received. This was measured from the time the manual scram relay opened. There is appreciably more delay than this in the various count rate meters. Measurements made by suddenly placing a neutron source before the detectors indicate that approximately 0.3 seconds are required for a scram signal to be generated. The overall system response time is therefore taken to be 0.4 seconds.

Figure 5-7 shows a typical inverse multiplication curve for one of the Nimbus assemblies. If the assumption is made that near critical $1/M=1-k$, the terminal slope corresponds to approximately $ 60 per inch of separation, or 6 cents per mil. The maximum reactivity increase rate should therefore not exceed $ 1 in 0.4 seconds or the ram speed should not exceed 40 mils/second. The actual ram speed during the last 1/2 inch of travel is 1/2 inch/minute or about 8 mils/second, giving a factor of five response times in the time required to add $1 of reactivity.

The terminal slope of an inverse multiplication curve generated by assembling two halves of a sphere is the largest slope in the curve, as shown in Figure 5-7, so use of this value is overly conservative for points beyond 1/2 inch separation where the system is sub-critical by many dollars. At 1/2 inch separation, the system is in the neighborhood of $40 - $50 subcritical. It is therefore reasonable to operate in this region at a higher ram speed than that for the final closure.

INVERSE MULTIPLICATION vs SEPARATION
BETWEEN HEMISPHERES

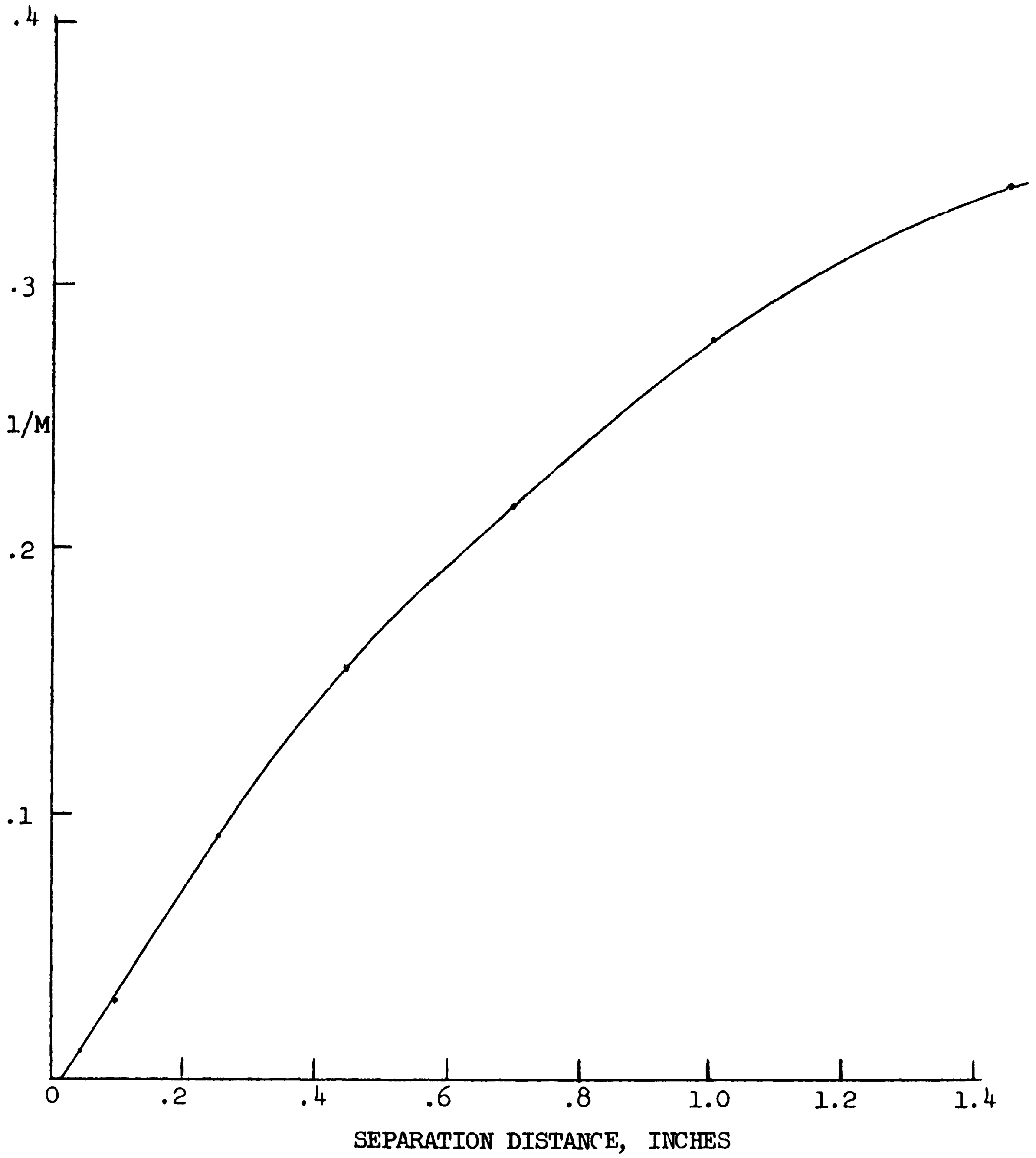


FIGURE 5-7

Operation at 5 inches per minute adds approximately \$1 in 0.4 seconds and is within the maximum reactivity increase rate limits. At 1/2 inch separation, the curve indicates approximately 30 \$/inch of separation.

5.3.7. Procedures

The following section is a copy of the assembly procedure that was prepared for the Nimbus program.

General

The Nimbus program involves a series of critical mass measurements on oralloy reflected with beryllium.

Purpose

The Nimbus assemblies are being undertaken to provide information on the above mentioned systems which will be basic to the normalization of computer codes.

Safety

The assemblies will be done in the west blockhouse of Building 110 on a remotely controlled vertical assembly machine. At least three counters will be used in conjunction with count rate meters which are part of the safety chain. The counters will be calibrated before each day's run. Plateaus will be checked at this time. Scram circuits will be tested prior to making a multiplying assembly. Positive spacers will be used between the halves of the assembly during closure. A health chemist will be present to monitor the assembly area during runs to check for possible buildup of contamination. Health Physics will position nuclear emulsion film in the assembly area to aid in the evaluation of any accidents which may occur. The scram system will be of the hydraulic bypass type depending on the force of gravity for separating the assembly. In addition to gravity, a hydralic accumulator will be built into the scram circuit so that initially the ram will be in powered scram. A pressure interlock in the accumulator will prevent assembly until there is sufficient stored pressure to insure a powered scram. All valves and interlocks on the assembly machine will be of a fail-safe design.

Equipment and Instrumentation

The assembly will be mounted on a machine designed especially for the Nimbus program. This machine will eliminate the use of a steel diaphragm to support the upper half of the assembly and has a support structure which will minimize the amount of mass adjacent to the assembly. The elimination of the steel diaphragm has increased the possibility of an assembly falling together due to the failure of the upper support structure. To offset this, three remotely controlled spacer arms will be in place between the assembly halves during closure. The spacer thicknesses can be varied by remote control so that an assembly can be completed without entering the experimental area during a run.

Two BF_3 Hansen type counters and two moderated LiI scintillation counters will be used to monitor the assemblies and to take experimental data. The counters will be operated by amplifier scaler units which will be connected to count rate meters.

Procedure

The assembly proper consists of nesting shells of oralloy and of beryllium made in such a way that a beryllium shell can be substituded for an oralloy shell at any place in the assembly.

The assemblies will be begun by determining the counter efficiencies with a bare mock-fission source located at the point on the machine corresponding to the assembly's center. Base rates will be determined by placing the source in the center of each beryllium configuration and determining a new effective counter efficiency which will modify the base rate.

Following the base rate determinations for the proposed configurations, the actual assembly will begin. The given core will be mounted in the lower half of its selected reflector and secured to the ram of the assembly machine. The upper portion of the refector will be secured to the upper support structure and the maximum positive spacers will be inserted between the halves. The spacers will be the following thicknesses: 1", .70", .45", .25", .175", .10", .075", .050", .025". The assembly will be run to a 2" separation and a count taken. This count rate, divided by the base rate for the configuration and spacing in question, will be referred to as the multiplication. The reciprocal of the multiplication will be plotted as a function of the separation of the halves. The 1" spacer will then be placed between the halves and the assembly run together. This will give two points on the curve, making a reasonable prediction of the safety of the next spacing possible. The assembly will continue with decreasing spacers until the plot shows that the next spacer will take the assembly past a multiplication of 100 or until closure is reached. The scrams will be set at a multiplication of 100.

VI. EVALUATION OF HYPOTHETICAL ACCIDENTS

6.1 GENERAL CONSIDERATIONS

In general the types of eventualities that can lead to nuclear excursions are the following:

1. Operator negligence
2. Engineering failure
3. Experimental accidents
4. Incorrect design premises
5. Acts of God
6. Sabotage and war

Sufficient experience has been gained by the Critical Assemblies Group over the past seven years to reduce the probability of an accident caused by a single one of the above contingencies to an acceptable low value but one which is not, unfortunately, zero. For example, provision of automatic shut down devices protects against operator negligence; fail-safe design protects against engineering failure etc., but experience at other laboratories has been that these are not sufficient to prevent all critical accidents. They have, however, been adequate to prevent any unplanned excursion from reaching an energy release sufficient to cause extensive faility damage or to create any appreciable radioactive contamination problem after the burst.

Two exceptions to the above statement can be mentioned here. If Borax I is considered to have been a critical facility, it was destroyed by an excursion which produced more power than had been planned. The other incident was a prompt burst which occurred in a plutonium solution at Hanford. As a result of the burst, plutonium contamination of the local area occurred, which required several days of clean up. On the other hand, the accident which destroyed Godiva I caused no damage beyond the assembly machine itself and resulted in very minor uranium oxide contamination of the floor area immediately adjacent to the machine.

If an accident has been postulated to occur, it is necessary to consider the shut down mechanism to estimate the magnitude of the resulting power excursion. For unmoderated metal systems, temperature effects are dominant. Physical expansion of the system lowers the density, which lowers the reactivity by increasing the leakage to capture ratio. The retardation between energy release and reactivity decrease due to thermal expansion is small because the expansion occurs in a time comparable to the sound transit time in the material.

In liquid systems, void formation in the liquid reduces the core density and reduces reactivity. This void formation appears to be associated with the fission fragments themselves, and is hence prompt. Heating of the solution causes thermal expansion and also raises the energy of the moderated neutrons. These effects combine to produce an effective shut down mechanism for such systems.

The statement that no criticality accident which has occurred has been large enough to cause major damage does not mean that such accidents cannot occur. A system which has no prompt inherent shut down mechanism can produce sufficient fissions to shut off the reaction by vaporization of core material and explosive disassembly of the core. The size of the accident then depends on the constraints imposed on the system. The Snoopy system, which is discussed in section 6.2., is a system which has no apparent shut down mechanism until the fuel foils have been vaporized. The analysis that is made shows a maximum credible accident of the order of 2×10^{18} fissions for no operating scrams with shut down accomplished by disassembly of the core.

A system where large amounts of reactivity can rapidly be added can also produce a very large excursion. The experience at Los Alamos with the Godiva experiments clearly indicate that in the absence of an initiating source many dollars of excess reactivity might be added before the chain reaction started. If this were to occur, yields in the range of 10^{19} to 10^{20} fissions could be obtained. In such a system, with its small heat capacity, this energy would appear primarily as kinetic energy and would produce effects similar to those associated with the detonation of several hundred pounds of high explosives.

These considerations point to the areas and manner in which caution should be exercised. Reactivity additions must be controlled - not only must planned additions be made slowly, but all unexpected and undesired reactivity increases must be prevented. Reactivity effects due to neutron reflection from operators' bodies or any other moving material must be anticipated and controlled. An initiating neutron source must always be present to prevent any unplanned reactivity increase from proceeding very far beyond prompt critical. And, wherever possible, the inherent shut down mechanism of the system should be well understood and the system designed to allow it to act as effectively as possible should this ever be required. Primary reliance for shut down on any critical assembly is, of course, placed on a fast acting and reliable scram system to prevent any inherent mechanisms from being required.

In sections 6.2. and 6.3. which follow, the consequence of the maximum credible accident is examined for the Snoopy and Nimbus systems. These are chosen as representative of the two major type systems with which experiments have been done at LRL - a large, heterogeneous, moderated core and a small, unmoderated, metal system.

For the Snoopy system, the assumed accident is a 2% step increase in reactivity beyond delayed critical, with no operable scrams. This type of reactivity change represents a thick hydrogeneous reflector some 24 inches wide being instantaneously applied to one side, or the instantaneous addition of 5% more core material. These conclusions are based on the information on reactivity as a function of reflection or core height increase given in section 5.2.6.

For the Nimbus system, the assumed accident is a ramp increase in reactivity of 70 cents per second, with no operating scrams, to a final reactivity of $3.10 above delayed critical. Such an accident would be the result of an operator error in overloading the core with 5 kilograms of oralloy, and the failure of both scram valves or of all neutron detector channels in the safety chain.

6.2. ACCIDENT EVALUATION FOR THE SNOOPY SYSTEM

The Snoopy system is a heterogeneous mixture of graphite plates and thin oralloy foils described in detail in section 5.2. It is a system where the only obvious inherent shut down mechanism is the vaporization of the foils and consequent blowing apart of the core. Other mechanisms not involving foil vaporization might be conjectured, but all depend on so many imponderables that it is difficult to treat them in any but a qualitative manner. The foils are typically one or two mils thick and they rest in ten mil deep slots in the graphite plates. The thermal contact between the plates and foils is poor, since they are only lightly in contact at a few points of their surface. This keeps almost all of the energy in the foils, at least until the foils have melted. Heating of the air in the slots by the foils will occur at a rapid rate, since many of the fission fragments formed in the foils can escape. This quantity of air, however, cannot expand to appreciable decrease the reactivity until temperatures above the melting point of uranium are reached. Such effects will aid the shut down, but they will be ignored in the analysis below. They thus act to make the final yield figure a pessimistic upper limit.

6.2.1. Type of Accident

The behavior of a typical Snoopy system is investigated for the case of a 2% step increase of reactivity above delayed critical with complete failure of all scrams. The sequence of events is considered to be the following:

a) A 2% step increase of reactivity above delayed critical.
b) A prompt period is generated, and at least some of the central foils vaporize.
c) Following vaporization of the foils, the core is dissassembled by the pressure of the uranium vapor.

It might be proper to insert at this point the behavior of the Honeycomb facility at Los Alamos during a prompt excursion. Honeycomb is a heterogenous, graphite oralloy foil assembly basically similar to the Snoopy systems. While being assembled at a reactivity increase rate of 1.0 dollar/second the system went prompt critical. The scram system operated properly in the design time of 0.4 seconds. The resulting excursion was estimated to have been 3.2×10^{16} fissions with no physical damage. The Snoopy scram system operates in very nearly the same time and the system as a whole should respond much the same way to a similar ramp increase.

6.2.2. Shut off by Disassembly

A typical Snoopy system will be taken to be a 48-1/2"x48-1/2"x42-1/2" core having a C/U equal to 1200. The core has a volume of 58 cubic feet and a mass of 2680 kilograms; fuel mass is 43 kilograms of uranium.

If the reactor period is given by $T = \ell^*/k_{ex}$ and ℓ^* is taken as 1.1×10^{-4} seconds, the resulting period will be 8.5 milliseconds. No reactivity loss is assumed for any increase in fuel temperature. When the fuel vaporizes, the self-shielding of the foils will be decreased as the fuel mixes with the moderator. As a pessimistic assumption, all of the 5% effect of the self-shielding is assumed lost even though mixing is negligible in short times. This corresponds to a 5% addition of fuel which will increase the reactivity by less than 0.5% in reactivity for these systems. The period will now be $1.1 \times 10^{-4}/0.018 = 6 \times 10^{-3}$ seconds.

Consider now the central region of the core enclosed by a cube 23 inches on a side. This will enclose one eighth of the volume of the core. Due to the flux distribution in the reactor, this volume will contain 35% of the power generated. It will, therefore, heat most rapidly and will determine the time scale of the disassembly. This region contains 7.25 cubic feet of graphite and 23 moles of uranium.

As the fuel foils commence to vaporize, the pressure in the 0.010 inch fuel slots commences to increase. This pressure will be the vapor pressure of the uranium at the temperature of the fuel foils. If it is assumed that the vaporized uranium acts as a perfect gas, the fractional amount of fuel that has vaporized is given by n_{vp}/n_u where

$n_u = \dfrac{P_{pg}V}{RT}$ = Pressure of a perfect gas in volume V, at temperature T, where the number of moles is equal to the total number of moles of uranium.

$n_{vp} = \dfrac{P_{vp}V}{RT}$ = The number of moles of uranium vaporized to give pressure P_{vp} in a volume V, at temperature T.

The work of Rauh and Thorne (ANL-5146) gives the vapor pressure of uranium as

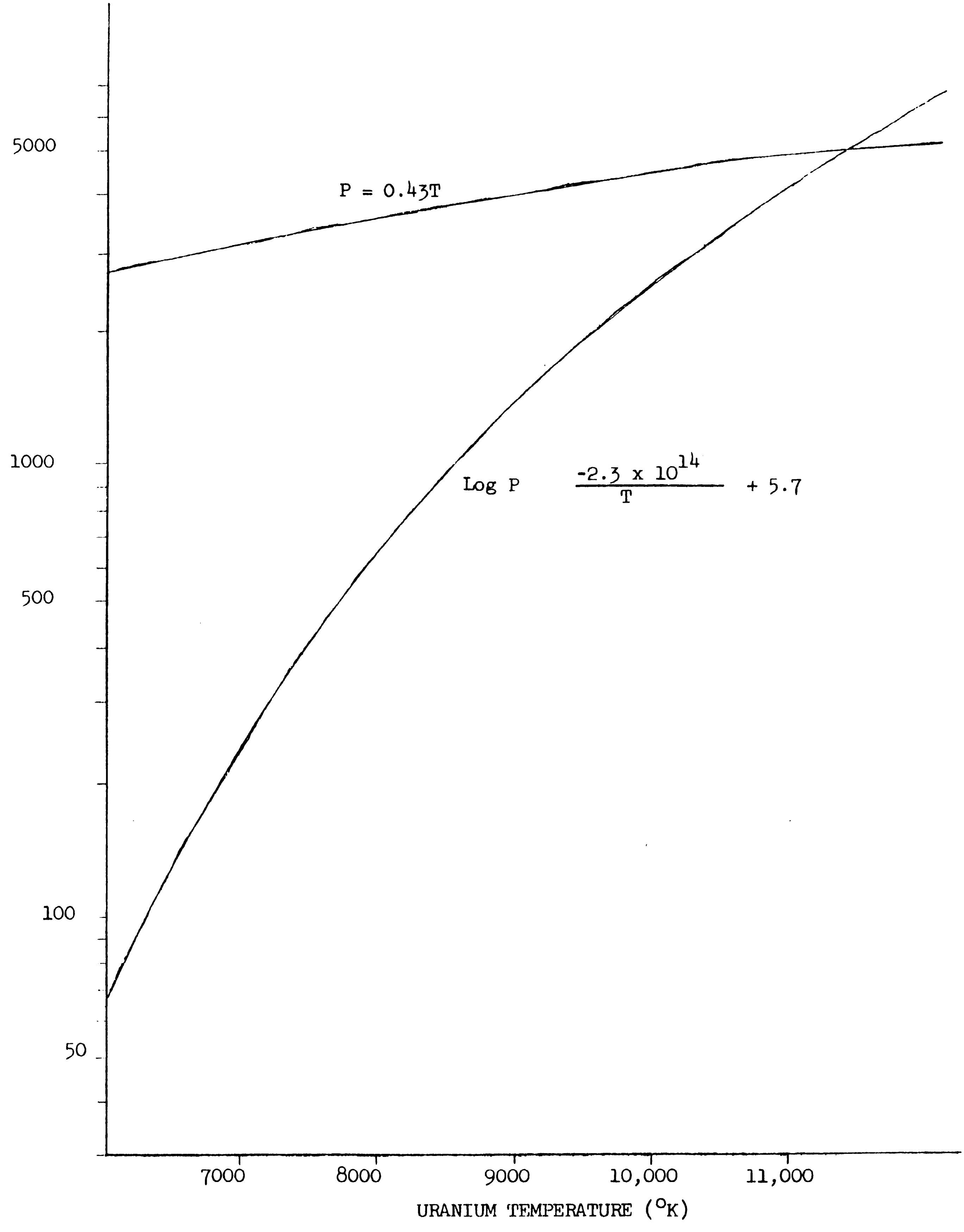
$$\log P_{vp} = - \frac{2.3 \times 10^4}{T} + 5.7 \quad \text{(atmospheres)}$$

Each foil is in a slot 6" x 6" x 0.010". The perfect gas pressure if all of the uranium vaporizes is then

$$P_{pg} = 0.43\ T \quad \text{(atmospheres)}$$

A plot of the vapor pressure and the perfect gas pressure is shown in Figure 6-0. Since the fractional quantity of uranium that has vaporized is P_{vp}/P_{pg}, it is obvious that less than ten per cent of the uranium is vaporized until the temperature exceeds 7000°C. The pressure, however, is substantial long before this. At 6000°C , for example, the pressure is 65 atmospheres. Since the only constraint on the system is the weight of the graphite, which is approximately 1.5 lbs/square inch or 0.1 atmosphere at the central plane, disassembly of the system will begin as soon as temperatures sufficient for vaporization are reached.

For the purpose of estimating the time required for disassembly, assume that the only force acting is that at the central plane. This is clearly a very conservative assumption, because each foil will act independently to force up the graphite above it, and there are some 85 foils in one 6" x 6" vertical stack. However, the flux distribution will produce a variable heating along the vertical axis, and the central foils will produce the largest effect. There is approximately 100 grams/cm^2 of graphite above the central plane. The information presented in section 5.2. indicates that one inch of core height is worth about 1% in reactivity for a typical system. Hence, removal of 2-1/2 inches is required to remove 2-1/2% reactivity. A 2-1/2%



PERFECT GAS AND URANIUM VAPOR PRESSURES
FIGURE 6-0

reactivity increase corresponds to a 6% mass increase. (2.5 inches/42 inches). The density decrease necessary to require a 6% mass increase is 3% ($M_c \propto 1/\rho^2$). If this is caused by expansion only in the vertical direction, this corresponds to 1.25 inches. Since disassembly in the vertical direction will be greatest in the center, decreasing to the edges, motion of 2-1/2 inches in the center will be considered sufficient to stop the reaction.

The time required to move the graphite 2-1/2 inches will depend on the pressure at the central plane. If the driving pressure is assumed to remain constant during the motion, then the time to move 2-1/2 inches is

Pressure (atm)	Time (sec.)
1	3.5×10^{-2}
10^2	3.5×10^{-3}
10^3	1.1×10^{-3}
10^4	3.5×10^{-4}

Thus, at temperatures which correspond to appreciable foil vaporization (6000 - 12000°C) the vapor pressure of the uranium is sufficient to disassemble the reactor in less than one generation (6×10^{-3}) seconds. As the foil gaps enlarge, the uranium which has not vaporized will do so and the material will then act as a perfect gas. The pressure behavior with time will be quite complex, but the assumption of constant pressure furnishes a reasonable approximation to the disassembly time. It is only necessary to observe that less than one generation is necessary for shut down, from the time that a temperature of 6000°C is reached.

The magnitude of the energy release is really fixed by the stipulation that the foils vaporize. This can be best appreciated by a consideration of the energy required to heat the foils, melt them, heat the molten metal, vaporize it and heat the vapor. No direct figures are available for the enthalpies of liquid or vaporous uranium, but the heat capacity for the liquid and vapor can be assumed to be equal to the solid. Then:

to heat the metal, $H = (1100^{o} - 300^{o}) \times 9 \frac{\text{cal}}{\text{mole}} = 7.2 \frac{\text{k cal}}{\text{mole}}$

$H_{\text{fusion}} = 2.5 \frac{\text{k cal}}{\text{mole}}$

$h_{\text{vaporization}} = 116.0 \frac{\text{k cal}}{\text{mole}}$

Total energy required to form vapor at 1100°C $= 125.7 \frac{\text{k cal}}{\text{mole}}$

To heat the vapor to 12000°, $H = (12000 - 1100) \times 9 \frac{\text{cal}}{\text{mol}} = 98.1 \frac{\text{k cal}}{\text{mole}}$

Thus, the total energy only varies between 126 k cal/mole and 224 k cal/mole whether the pressure in the foil gap is 1 atmosphere or 5000 atmospheres.

A release of 224 k cal/mole throughout the central 23 inch cube will be sufficient, on the basis of the disassembly times, to terminate the excursion. This is approximately 5 megacalories. The remaining 7/8 of the reactor will have 65% of the total fissions or about 9 megacalories. The total excursion is thus certainly less than 14 megacalories or 1.7×10^{18} fissions. A number of pessimistic assumptions have been made in the estimate. These are, that the air in the gap does not heat and contribute to the disassembly, that no uranium vapor leaves the reactor when it is formed, that all disassembly is accomplished by the foils in the central plane instead of all 85 in one vertical stack, and that only vertical disassembly takes place. Thus, 1.7×10^{18} fissions is regarded as a very pessimistic upper limit to an excursion which is terminated by physical disassembly of the reactor.

Two other points should be mentioned here. First, shocks are not assumed to develop in the graphite during disassembly. Sound speed in the graphite is 2.8×10^{5} cm/second, using 4.3×10^{9} gm/cm^{2} as the elastic modulus of graphite. The assembly is roughly a sphere with a 60 centimeter radius, so 2.1×10^{-4} seconds is required for a signal to reach the outer surface. The pressure signal was assumed to occur in the order of one generation (6×10^{-3} seconds) so no shocks should develop. The second point is that the thermal diffusivity of graphite is too small to absorb appreciable energy from the vapor during the assembly time. This is important in preventing cooling and condensation of the vapor on the graphite. The diffusivity is $k/\rho C_p$ and if $k = 0.05$ cal/sec/cm/^{o}C, the heat can penetrate only about 0.04 seconds in one generation.

6.3 ACCIDENT EVALUATION FOR THE NIMBUS SYSTEM

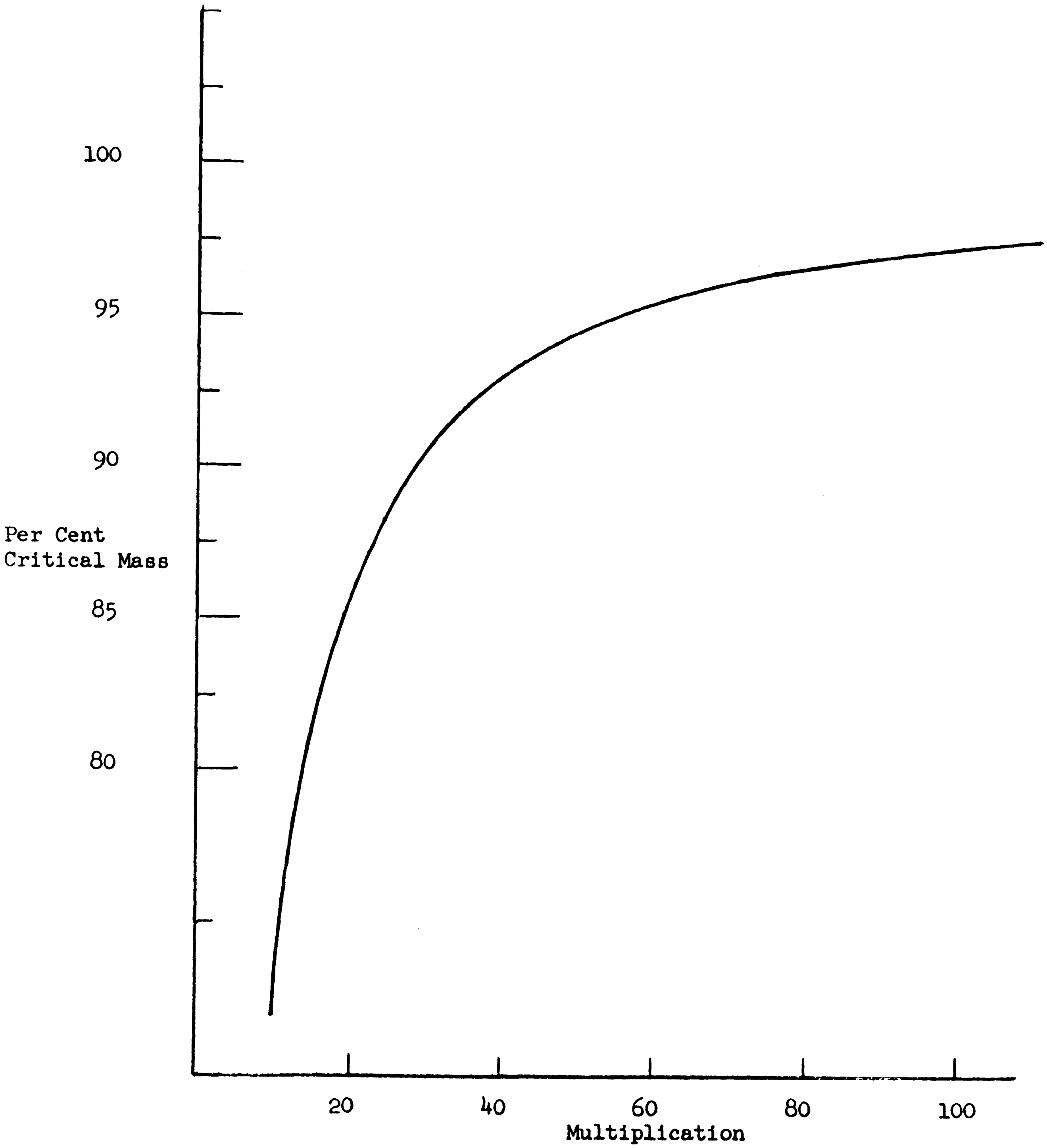
6.3.1. Type of Accident

A metal system, such as that in the Nimbus experiments, is characterized by a small size, small heat capacity and very fast generation time. These properties mean, in general, a more violent physical reaction to a large excursion, but a smaller total quantity of radiation then in the larger systems.

The type of accident investigated for this system is one where a double failure has taken place. The Nimbus system core is composed of nesting oralloy shells. The assumption is made that a core having a multiplication of 75 has been constructed and disassembled on the Nimbus machine. The operator now erroneously adds the next set of core shells, which weigh approximately five kilograms. Assembly is started, and the scram mechanism does not operate.

6.3.2. Unreflected System

The addition of 5 kilograms of oralloy to a system which is at a multiplication of 75 will produce a system which is super prompt critical. Figure 6-1, which is taken from LA-1604, shows that at a multiplication of 75 a bare oralloy system has 96.5% of the delayed critical mass. The bare spherical critical mass for oralloy is 52 kilograms, so the 3.5% required to bring the M = 75 system to delayed critical is 1.8 kg. Thus, the addition of 5 kg produces a system which is 3.2 kg above delayed critical. LA-1604 also gives the value of 2% or 1.04 kg as the surface mass increment between delayed and prompt critical. The addition of 3.2 kg beyond delayed critical, which is 6.2% of the delayed critical mass, should therefore yield a reactivity of \$3.10 above delayed critical for the fully assembled system.



PERCENT OF CRITICAL MASS VS. MULTIPLICATION (OY-SPHERE)LA1604 P.33

FIGURE 6-1

The reactivity change per second must now be estimated in order to calculate the behavior of the system during assembly. If we assume that a one mil separation of the two halves of the assembly is equivalent to removal of oralloy from the assembly, then

1. $\Delta m/\Delta s = \pi R^2 \rho \times 0.00254 = 11.4$ gm/m
2. \$1.00 = 1.04 kg of surface mass
3. Central mass is six times as effective as surface mass (Reactor Handbook, Vol. 1, p. 528).
4. $d\gamma/ds = 0.066$ \$/mil (this is in reasonable agreement with the value of 0.06 \$/mil for the experiment described in 5.3.6.)
5. For a ram speed of 0.500 inches/minute,
   $d\rho/dt = 55$ cents/second

On the other hand, if the effect of a one mil diametral gap is assumed to be equivalent to a uniform decrease in density, the rate of change of reactivity is found to be 37 cents/second. In the following calculations, a pessimistic increase rate of 70 cents/second is assumed.

A code which is applicable to this type of calculation is the Dane code. It is a reactor kinetics code which includes a temperature, temperature coefficient coupling equation. The Dane code solves the following eight coupled first order differential equations:

$$\dot{n} = \rho(t) + \alpha(T) - \beta\, r(T)\ \ n + 4(T) \sum_{i=1}^{6} \beta_i d_i + S(t)$$

$$\dot{d}_i = \lambda_i (n - d_i) \qquad i = 1, ---, 6$$

$$\dot{T} = \frac{n}{\sigma\, C_{Pc}}$$

where

n = Power density (ergs/cm^3/sec)

$\rho(t)$ = programmed reactivity

$= \alpha_{Dc} (D_o + Rt)$

$r(T) = \gamma/\ell^* = \alpha_{Dc}/\beta = 1.59 \times 10^8\ \mathrm{sec}^{-1}$

d_i = normalized concentration of delayed neutron precursors (ergs/cm^3/sec)

$\lambda_i, \beta_i, \beta$ = usual delayed neutron constants

$S(t)$ = source strength ($ergs/cm^3/sec^2$)

T = Core temp (^oK)

σ = density

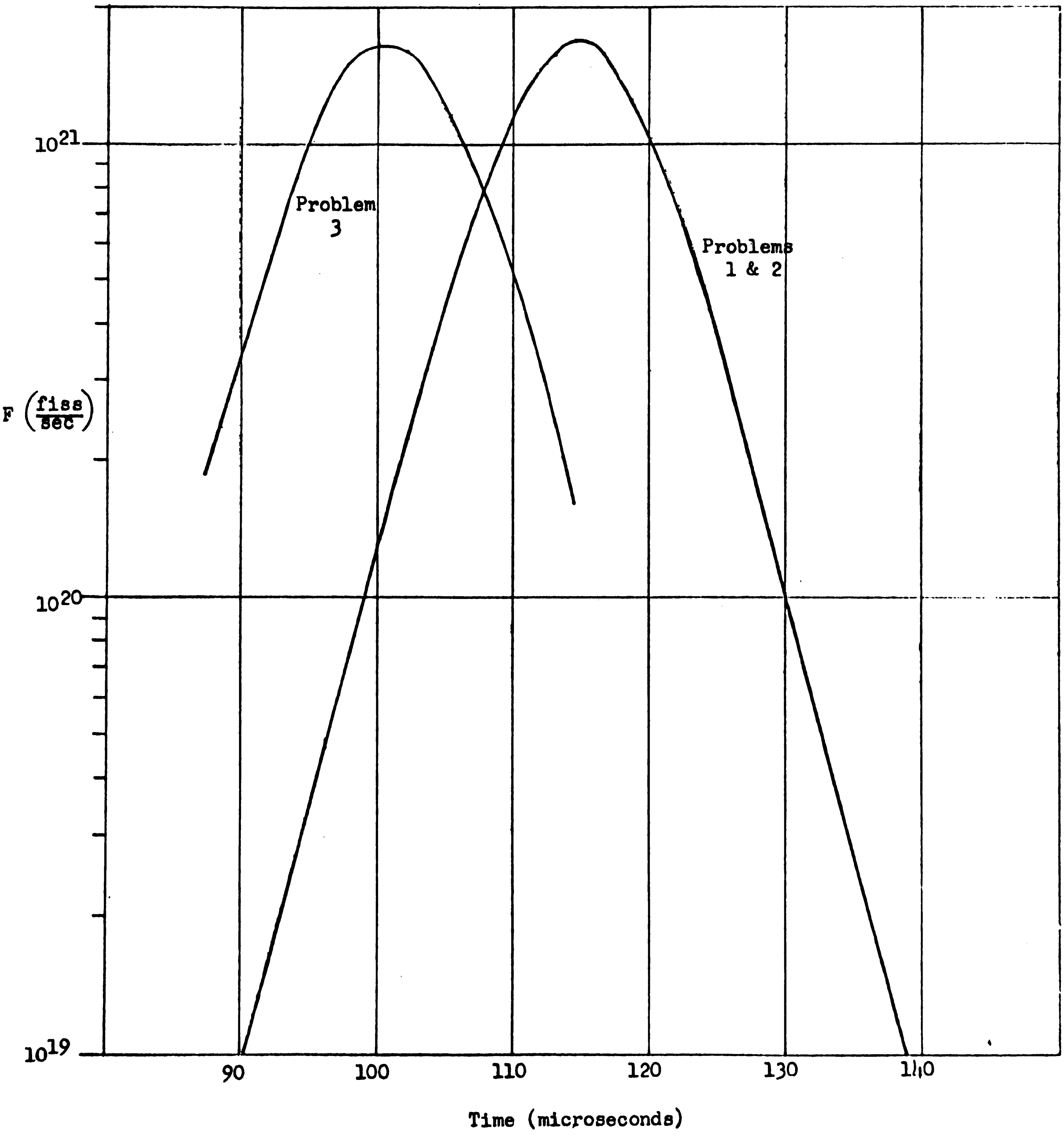
D_{Pc} = heat capacity of core ($ergs/^oK/gm$)

One difficulty in using this code is that neither the initial power of the systems nor the specific heat of the uranium is well known. The initial power will depend on the neutron emission of the driving source and the assumed multiplication when the calculation starts. The specific heat of uranium is 0.028 calores per gram at room temperature, increasing to 0.040 calories per gram at 600°C. In the calculation it is necessary to use a constant value for the specific heat. In order to check the results of making reasonable assumptions for these two cases, three problems were run for the Godiva I accident, which produced 1.2×10^{17} fissions. The reactivity change here was a step increase of $1.25 above delayed critical. The assumptions and results are shown in the table below.

Problem	Initial Power	Specific Heat	Yield
1	0.001 watts	0.028 cal/gm/°K	1.56×10^{17} fissions
2	0.001 watts	0.040 cal/gm/°K	1.56×10^{17} fissions
3	0.100 watts	0.040 cal/gm/°K	1.56×10^{17} fissions

A plot of the results is shown in Figure 6-2. From this it is seen that only the time scale is affected by the choice of source strength and specific heat. The calculated yield is also in reasonable agreement with the experimentally observed value, and is sufficiently good to warrant some confidence in the results for other all metal systems.

The assumed accident (a 70 cents/second ramp increase of reactivity to a final reactivity of $3.10 above delayed critical) was run with the same three different specific heat and initial power assumptions as for the Godiva accident given above. In each case the integrated yield was the same and was equal to 2.2×10^{17} fissions.



FISSION RATE VERSUS TIME FOR GODIVA I CALCULATION

FIGURE 6-2

A plot of one of the runs is shown in Figure 6-3. When the system becomes prompt critical, a spike is produced which produces almost all of the energy. This heats the system and reduces the reactivity. The reactivity continues to increase for three more seconds due to the assembly motion, and during this time the power level of approximately one megawatt causes sufficient temperature increase to calcel the extra reactivity. When the reactivity increase stops at three seconds after prompt critical, the power level breaks and begins to fall.

According to these calculations, the postulated accident results in a total number of fissions only slightly higher than the Godiva I accident. The results of such an accident would warp and damage the assembly parts and would do some damage to the lightly constructed assembly machine. There would be no release of active material from the vault and little contamination of the vault itself. Personnel exposures would be less than 1 rem as shown in section 7.1.

A similar calculation, using the appropriate constants for Pu^{239}, was also run for a 70 cents/second assembly rate. The results of this run are shown in Figure 6-4. The integrated fission yield was 7.6×10^{16} fissions. The yield is smaller in this case primarily because of the smaller mass and hence smaller heat capacity of the critical plutonium system. An all metal plutonium system is thus expected to behave in a way quite similar to a uranium system, as far as burst size is concerned for the same magnitude of error.

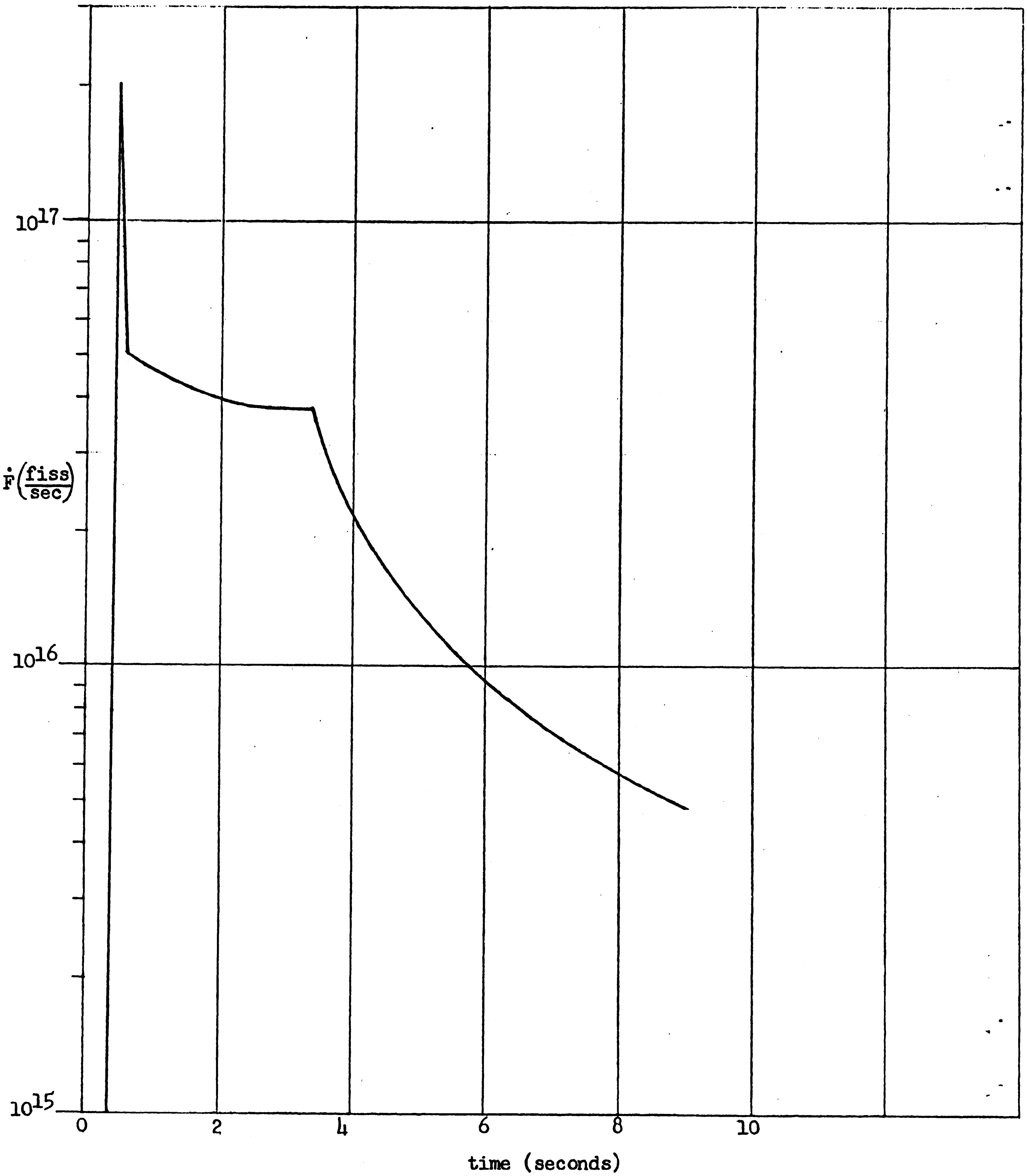
6.3.3. Reflected System

An approximate comparison between the yield for an unreflected system and a reflected system may be made as follows:

$$mc = \text{unreflected critical mass} = c\rho_c^2$$
$$mc^1 = \text{reflected critical mass} = C^1\rho_c^{-x};\ x \leq 2$$

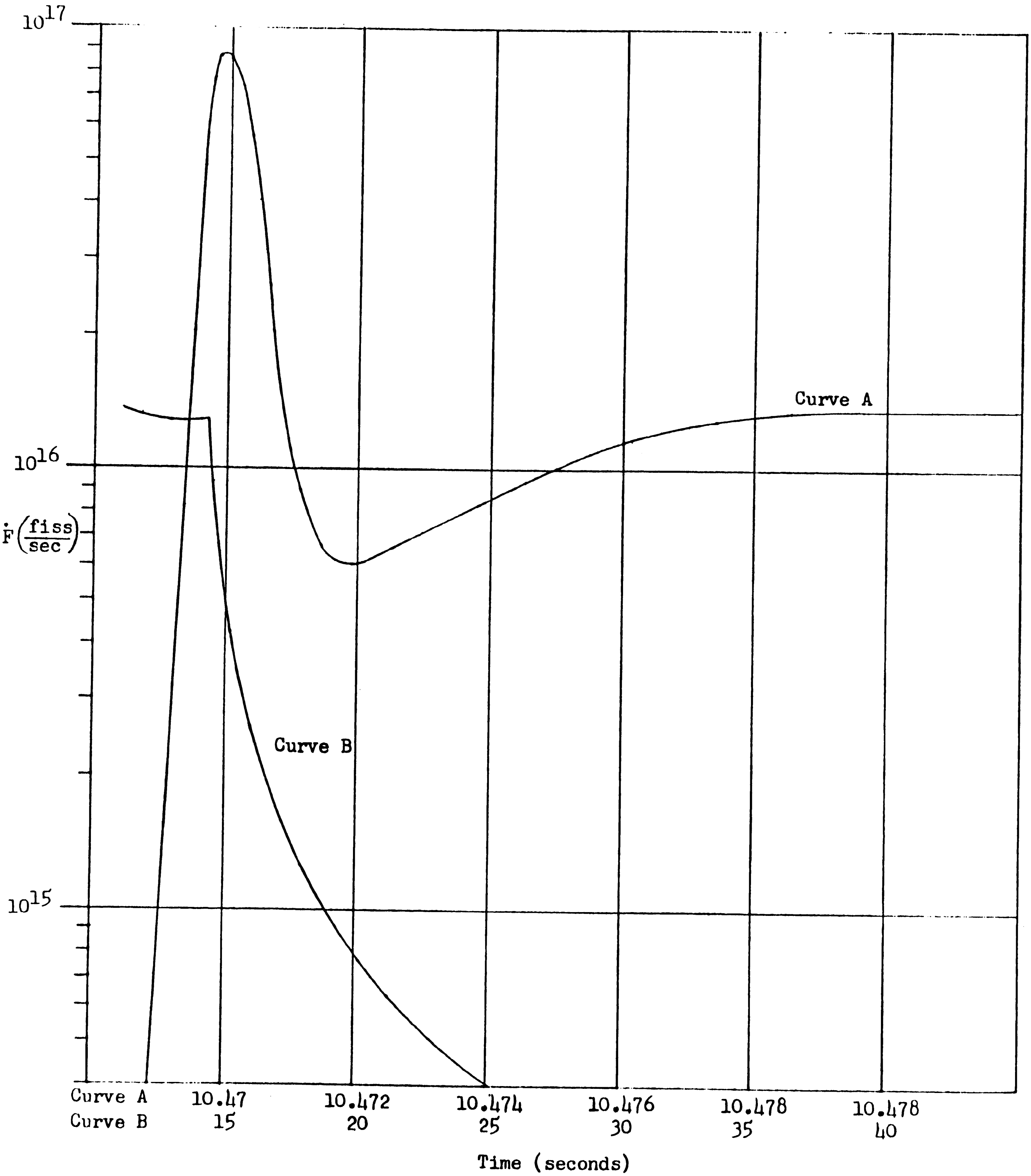
where ρ_c is the core density. The density in either case, depends on the total fissions F as

$$\rho = \frac{\rho_0}{1 + KF}$$



FISSION RATE VERSUS TIME FOR NIMBUS ACCIDENT NO. 1 (70¢/SECOND)

FIGURE 6-3



FISSION RATE VERSUS TIME FOR PLUTONIUM ACCIDENT (70¢/SEC)

FIGURE 6-4

where K is determined by the thermal coefficient of expansion and the specific heat.

$$\frac{dmc^{1}}{mc^{1}} = -x \frac{d\rho c}{\rho c}$$

$$\frac{dmc}{mc} = -2 \frac{d\rho}{\rho}$$

Assuming reactivity to be proportioned to the quantities on the left, then if $d\rho c/\rho c$ and $d\rho/\rho$ are the fractional changes in density required for shut down:

$$\frac{d\rho c}{\rho c} = \frac{2}{x} \frac{d\rho}{\rho}$$

$$\frac{F}{1 + KF} = \frac{2}{x} \frac{Fo}{1 + KF_o}$$

where F_o is the fission yield of the unreflected system. Thus:

$$F = \frac{(2/x)\,Fo}{1 + \left(1 - \frac{2}{x}\right) KF_o}$$

For an infinite natural U reflector x is 1.2 (NUCL <u>15</u> 92 (June 1957)) and for a Be reflector

Reflector Thickness	x
25 cm	1.2
5 "	1.6
2 "	1.8
0 "	2.0

Accordingly the factor $\left(1 = \frac{2}{x}\right)$ varies between 0 and -2/3. Furthermore $KF_o << 1$ so that

$$F \cong \frac{2}{x} Fo$$

and the fission yield for a reflected system can be larger than that of a corresponding untamped system only by a factor of the order of 2.

This result is in agreement with the statement: "One concludes ... that for metal assemblies, the presence or absence of tamper makes little difference as far as the energy release associated with a given assembly rate is concerned." (LA-1441, p. 20).

VII. CONSEQUENCES OF CRITICAL ACCIDENTS

In the event that a critical accident does occur in the facility, protection should be provided to shield operating personnel from the direct hazards associated with the accident. Provision must also be made to prevent exposure or contamination to people and land both on and off site. The safety features of the critical facility are examined with respect to the following points:

1. Radiation shielding.
2. Containment of fission products following an accident.

Since both the past experience with critical accidents and the accident analysis that have been made in this report indicate that 10^{18} fissions is a reasonable but high value for a credible burst, the evaluation of hazards will be done on the basis of an accident that has produced 10^{18} fissions. The radiation level results scale linearly with burst size, of course.

7.1. RADIATION SHIELDING

Various calculations have been made to evaluate the dose received through the different leakage paths in the three vaults. In addition, measurements of the neutron and gamma flux have been made throughout the building while Snoopy type systems have been operating in the East vault. These actual measured radiation levels are in all cases below those calculated by the various shielding calculations due to the conservative manner in which shielding calculations are always done. The only shielding feature which has not been checked by actual measurement is the personnel door on the new vault in the containment building. The calculations for this are given in section 7.1.2. below.

The results of the measurements and calculations lead to the following conclusions:

a) The largest neutron dose would be produced by an excursion in the East vault, since it has less roof shielding than the other two areas. The maximum dose for a 10^{18} burst in the East vault anywhere outside the vaults would be 11 rem. This would be at the entrance of the East vault maze. In normal working areas the dose would be less than 5 rem.

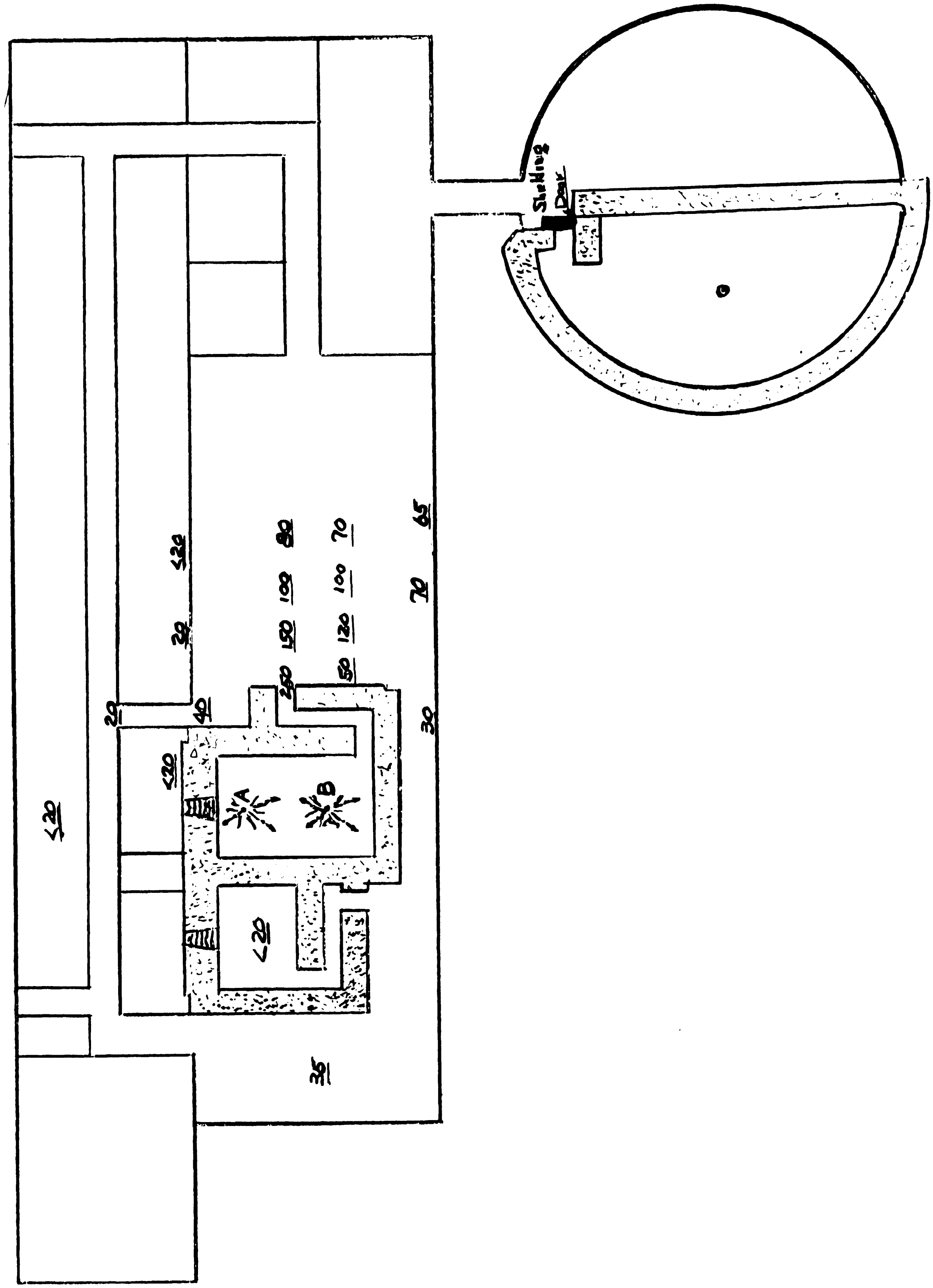
b) The maximum gamma ray dose for a 10^{18} burst would be 1.8 rem and would be produced by an excursion in the East vault. This dose would be received by a person standing by the control room side of the water window.

7.1.1. Radiation Measurements

Exposure to personnel can occur by gamma and neutron penetration through the concrete walls and through the water windows, by neutron and gamma scattering over the walls and through the access mazes and doors, and by gammas from thermal neutron capture in the water windows. In order to measure the penetration through the walls and water window, an assembly was run at 10 watts in the East vault. The center of the assembly was seven feet from the window, in the normal working position. It is indicated as the point A in Figure 7-1. The gamma radiation rate was measured to be 1.8 mr/hour at the surface of the window. A gamma rate was not measureable at the wall surface. The neutron penetration through the window and through the wall was below the measurable limit, which was 20 neutrons/cm^2/sec.

A second assembly was run at position B, as shown in Figure 7-1. Its center was ten feet from the west wall and ten feet from the south wall. This assembly was used to determine the skyshine and scattering down the maze. It was run at 6 watts. At this power level, the gamma dose rate was below 1 mr/hour at all points outside the vault. The epi-cadmium neutron counting rates found at various points in the building are shown by the numbers in Figure 7-1. All numbers are neutrons per square centimeter per second.

A measurement of the average neutron energy of these neutrons was made measuring the attenuation length for polyethylene. The curve so obtained can be compared to those obtained with known energies of neutrons and the average energy inferred. An average energy of 70 kilovolts was obtained in this way. A negligible amount of thermal neutrons were present in the neutrons counted. The maximum permissible dose rate for 70 kev neutrons, based on 100 mrem/weeks (40 hours)



NEUTRON LEVELS FOR REACTOR B AT 6 WATTS

FIGURE 7-1

is 85 neutrons/cm^2/sec. Using these numbers, 1 rem of 70 kev neutrons is $1.2 \times 10^8/cm^2$. Then, if 6 watts or 1.8×10^{11} fissions/second produce 100 neutrons/cm^2/second at a given point, a 10^{18} burst will produce 5.5×10^8 neutrons/cm^2 at that point, or about 4.5 rem. Examination of Figure 7-1 will show that there were 250 neutrons/cm^2/second at the maze entrance and a level of from 80 to 150 in the main bay area. The threshold of detectability was 20 neutrons/cm^2/second. The West vault and the containment building vault will both have lower radiation levels outside, due primarily to the much more effective roof shielding in these areas. The West vault has 30 inches of concrete and the containment vault has 24 inches. The water window in the West vault is eighteen inches thicker than that in the East vault. The mazes appear to be leakage paths for neutrons, but not serious ones. The measurements indicate that perhaps half the neutron level at the maze entrance is due to skyshine.

7.1.2. Calculations for Personnel Door

This door was designed to make a door having the shielding properties of 5 feet of normal density concrete, with appreciably less weight. The door which was built on the basis of the following calculations has 58 centimeters of paraffin loaded with boric acid to give 5% by weight of natural boron. This side faces the interior of the vault. The exterior surface of the door is 4 centimeters of lead. The total mass is 103 grams/cm^3. A concrete door with a density of 2.3 grams/cm^3 and 5 feet thick has a mass of 350 grams/cm^3, so a substantial weight saving was realized.

The dose attenuation for 5 feet of concrete for fission neutrons was obtained from the A.I.P. Handbook 8-169 as approximately 10^{-6}. For fission gammas, formulae given in Rockwell, p.243 gives 3.7×10^{-6} for 5 feet of normal density concrete. The door must have dose attenuation factors at least this high to be acceptable.

The arrangement of the shielding walls is such (see 7-1) that the door does not receive direct radiation from an assembly located in the center of the vault, in the design position. All radiation incident on the door is radiation which has scattered around a corner, and it is first necessary to calculate the attenuation produced by such scattering. For neutrons, the assumption was made that a fission spectrum neutron source can be well represented by a 5 mev incident neutron beam. This is compatable with the procedures used in the A.I.P. Handbook. Hence, a beam of 5 mev neutrons was assumed to be incident on the concrete wall in the center of the wall area seen by the door. The concrete was assumed to be SiO_2 with an average total cross section of 1.7 barns (assumed elastic with no energy loss). The scattering was assumed to be isotropic in the laboratory system. The average solid angle of the door was taken to be $6x10^{-2}$ steradians. The beam on being scattered was estimated to be attenuated by an average of two mean free paths, to account for penetration into the concrete. Using these assumptions, the attenuation due to the scattering around the corner for neutrons was found to be $1.3x10^{-2}$.

The gamma scattering around the corner is much more favorable due to the large energy loss when the gamma ray scatters. The average single scatter angle is about 100°, from the geometry of the vault. The cross section was conservatively assumed to be the Thompson cross section. The scattered gammas were also assumed to be attenuated by two mean free paths. The energy of a 5 mev gamma after a 100° scatter is 0.38 mev. The scattering attenuation was found to be $6x10^{-2}$, which appears to be less than that for neutrons. The dose decrease is much larger however, due to the large energy loss for the gammas.

The dose attenuation for a 58 centimeter CH_2 plus 4 centimeter lead door can now be estimated. The neutron capture in the boron is neglected, so the results will be conservative. The dose attenuation is De^{-ux} where D is the buildup factor, u is the absorption coefficient and x is the shield thickness. The buildup factor for 5 mev neutrons in the door was taken to be 8, based on Monte Carlo calculations made for the Convair Shielding Data Manual. The dose attenuation is approximately $6x10^{-5}$, which combined with the scattering attenuation gives a total attenuation of $8x10^{-7}$ for the primary neutrons.

The gamma attenuation calculation was complicated by lack of knowledge on gamma buildup factors for composite shields. Linear buildups were assumed. That is

$$\text{Attenuation} = D_{CH_2}\, e^{-(ux)_{CH_2}}\; D_{Pb}\, e^{-(ux)_{Pb}}$$

The buildup factor for water was substituted for CH_2 assuming Compton scattering and a correction for the electron densities. The absorption coefficients used were taken from the Convair Shielding Data Manual. The dose attenuation obtained in this way was 3.6×10^{-5} for the scattered gammas or a total attenuation for the primary gammas of about 2×10^{-6}. This attenuation cannot be directly compared to that of concrete because of the energy difference of the gammas. However, an attenuation of 10^{-6} at the scattered energy should be conservatively safe.

No direct safety factors were put into the calculations, but all assumptions were made in the conservative direction, i.e., elastic, isotropic scattering of neutrons, using the Thompson cross section for the gamma rays etc. Inelastic neutron scattering gamma rays and activation gamma rays were investigated and found to be negligible.

7.2. CONTAINMENT OF FISSION PRODUCTS

If a review is made of the fifteen or so critical accidents that have occurred in the United States to date, certain conclusions can be reached which can provide some direction in evaluating the consequences of critical accidents. These are, briefly, that no critical accident has ever produced appreciable damage to the facility in which it ocurred and that no critical accident has ever resulted in contamination beyond the facility in which it occurred. Further, however, three fatalities have been caused by radiation bursts and more than twenty-five persons have received sub-lethal but large doses of radiation. It thus appears that the place of principle hazard is actually in the assembly area itself and the persons most in danger are the operators. Even people in the same building have, in all past accidents, been in little or no danger from the burst. For this reason, the major part of the preceding pages has been devoted to a description and analysis of the administrative controls and experimental procedures which are primarily designed to protect the operators. It is in this area that lives have been lost in the past and it is in this area that the greatest hazard lies in the future.

The past accidents are, of course, not likely to be the whole story. Critical accidents have occurred at the rate of one or two per year since critical assembly work was begun. Since mechanisms for a large excursion do exist, it is certainly possible that one might occur in the future. However, a critical facility never has the inventory of fission products that a reactor has. The largest excursion known to date (at Arco, Idaho, on October 16, 1959) had approximately 4×10^{19} fissions. This is somewhat over 1000 megawatt seconds. All other accidents have been less than 10% of this figure, and as for the radiation shielding case it appears reasonable to consider a 33 megawatt-second or 10^{18} fission accident.

In order to evaluate the hazard from the release of fission products, it is necessary to estimate how many are freed from the fuel and then to estimate how many of these are allowed to escape from the vault. For experiments conducted in the containment building vault and the West vault, a triple failure is required before any radioactive material can escape from the test cell, and for the East vault a double failure is required. On this basis, it is hardly credible that any will escape from the cells.

For the West vault and the containment area vault the following safety features are incorporated:

a) Both areas exhaust through high efficiency filters. As long as these filters are intact, only minute quantities of non-gaseous material can be exhausted from the cell through the ventilation system.

b) If the filter should fail, air samplers will automatically cause the valves and dampers in the exhaust lines to close if activity above the natural radon background is in the exhaust air.

c) If an accident should occur the operator is to push the alarm button and the building seal button. Either of these closes the exhaust and intake dampers and valves.

Thus for radioactive material to be blown out the exhaust air duct, the operator must fail to sound the alarm following an accident, the filter must fail and the air sampler must fail.

For the East vault, the same considerations apply, with the exception that the exhaust duct cannot be sealed. The procedure in this case is to turn off the ventilating blower if the filter should fail. The vault is then at atmospheric pressure and diffusion of the activity takes place at a rate proportional to the size of the particles in the air. The diffusion path is through a duct to a point 50 feet above the ground before any release can take place. Referring again to the past criticality accidents that have occurred, three cases are pertinent at this point. On November 16, 1951, an excursion of i x 10^{16} fissions occurred at Hanford in an assembly of plutonium nitrate in water solution. Some of the solution was forced out of the system and contaminated the experimental area. Contamination beyond this area did not occur. On February 1, 1956, a burst of 1.6 x 10^{17} fissions occurred at Oak Ridge in a cylinder of uranium oxyfluoride water solution. Several liters of solution were forced out of the cylinder. The local area was heavily contaminated and required several days of clean up. Contamination outside the assembly area did not occur. On February 12, 1957, Godiva I sustained a burst of 1.2 x 10^{17} fissions at Los Alamos. Several grams of uranium oxide were formed and blown or spalled from the assembly. These were deposited within a few feet of the assembly machine, and decontamination was accomplished without difficulty. Contamination outside of the test area did not occur.

From the above accidents, it is apparent that the particles formed in a critical burst tend to be relatively large and heavy. They are rapidly deposited in the immediate area of the accident and do not tend to diffuse through available air paths, even when these are large in area. For these reasons, contamination beyond the vault areas for a 10^{18} burst is not considered to be a hazard as great as that present in chemical explosions which might occur in chemical plants handling radioactive materials.

7.2.1. Release of Fission Products

In order to estimate the severity of the problem involved with the release of activity to the atmosphere, the following assumptions will be made:

1. An accident of 10^{18} fissions has occurred.
2. This accident has vaporized 6 kg. of uranium, which is 10% of the total fuel present.
3. The filters in the exhaust air ducts are broken.
4. Neither the operator nor the air monitor stops the blowers or seals the vault.
5. All the fission products in the 6 kg. of vaporized material are released to the air.
6. No mixing of incoming air occurs with the air in the vault.

Then, on the basis of these assumptions, all of the fission products will be released to the atmosphere in 7-1/2 minutes assuming the East vault is the site of the accident. The total fission product activity for a 10^{18} burst will be approximately 25,000 curies 7-1/2 minutes after the burst. Ten per cent of this will have been expelled in 7500 cubic feet of air, so the initial concentration will be approximately 0.33 curies per cubic foot. The dilution of this cloud can be found from the formula for cloud expansion during average conditions as

$$\text{Cloud Volume} = \left[\pi^{\frac{1}{2}} C \times \frac{2 - n}{2} \right]^3 \text{ meters }^3$$

The fission product concentration is then:

Distance	Concentration	Exposure Time for 100 Mr. Inhalation Dose
0 meters	9 C/M^3	0
10 "	0.3 C/M^3	0
30 "	1.1×10^{-2} C/M^3	3.6 Sec.
100	3×10^{-4} C/M^3	140 sec.
300 (Edge of site)	1.1×10^{-5} C/M^3	3600 sec.

The exposure time for 100 mr is calculated assuming a dose of 2.5 R per curie per cubic meter per second for a person in the cloud.

The cloud gamma dose can be estimated from Table 8.1 in Meterology and Atomic Energy for average conditions. If it is assumed that the cloud height is between 0 and 50 meters, the values given below pertain.

d(meters)	Gamma Dose (Roentgens) h = 0 meters	h = 50 meters
30	21	0.064
300	0.168	0.035
3000	7.7×10^{-4}	0.001

In actual practice, vaporization and deposition of plutonium outside the vaults would represent a far more serious hazard, should it occur, than the sort of fission product release described above. A recent chemical explosion at Oak Ridge is reported to have released 600 milligrams of plutonium and to have contaminated some four acres of buildings and grounds. The extremely low biological tolerance to plutonium dictates that no plutonium be released in any accident, and the critical facility has been designed to accomplish this. To this date, the manifold safety features built into the facility have never been tested in an actual accident, but continual administrative and procedural vigilance insures that they are always ready for an emergency.

Should an accident occur and appreciable contamination result either inside or outside of the vaults, the LRL Hazards Control organization is available to assist the Neutronics Division. The Hazards Control group is staffed to conduct all types of monitoring and decontamination operations, with a record of fifteen years of experience at Berkeley and at Livermore. This group has daily occasion to work with all types of radioactive material, from that resulting from megaton bomb explosions to that from high current accelerators. Any conceivable accident in the critical facility could pose little in the way of an unexpected problem to this group.

VIII. DISASTER PLAN FOR BUILDING 110

Building 110 is primarily a critical assembly and reactor testing facility. Potential disasters which are internally generated will be generally related to a critical accident or radioactive spill. Other types of disaster, such as fire, release of noxious fumes, etc. will be mentioned, but the primary purpose of this plan will be to indicate the actions appropriate to the special class of critical accidents.

The building has three experimental areas where criticality work takes place. These are the west blockhouse, the east blockhouse, and the containment building. Procedures for emergency action are similar for these three areas, so they will be treated under the same general discussion. Problems peculiar to any one area will be stated when that particular area is being dealt with.

8.1. TYPES OF INCIDENTS WHICH WILL BE CONSIDERED AS A DISASTER

8.1.1. Nuclear

1. Any assembly of fissile material which achieves prompt criticality, and produces an uncontrolled excursion.
2. Any release of radioactive material to the general environment of the building.

8.1.2. Non-Nuclear

1. Fires and explosions (not associated with radioactive materials).
2. Release of toxic or noxious substances to the general environment.
3. Natural disasters
    a. Earthquake
    b. Floods
    c. Windstorms
    d. Lightning
4. Man-made Disasters
    a. Attack by hostile forces.
    b. Objects striking building, such as falling aircraft, runaway vehicles, etc.
    c. Explosions in other parts of the laboratory.

d. Receipt of evacuation orders for incidents not related to Building 110, but posing a hazard (such as LPTR releasing radioactivity to the outside air).

8.2. GENERAL PROCEDURES

In the event of a disaster signal which has been initiated for any cause whatever, the following general procedures are to be followed:

A. All assemblies of fissionable material will be scrammed.

B. All machines which are being operated such as machine tools, etc. will be turned off.

C. Torches and other open flames will be extinguished.

D. The person initiating the alarm should call the emergency number (333) and explain the cause of the alarm. This will be done from the guard gate at the entrance to the exclusion area. The primary guidance in the matter of what to do is to remember that it may be a considerable length of time before anyone can return to the building. A disaster can be compounded by thoughtless actions on the part of personnel and action motivated by panic must be avoided.

8.3. ALARMS

The general disaster alarms will be situated so that complete coverage of the building will be obtained. The alarms will not depend upon external electrical power for their operation. The alarm will be actuated from the three control rooms and the main office. All persons working in and around the building will be informed of what the alarm sounds like, what it means, and what to do when it is sounded. Actuation of the alarm will automatically scram all assembly machines and reactors in the building. Disaster drills will be carried out at unannounced times.

8.4. EVACUATION PROCEDURES

The nearest exit should be used when evacuating the building. Once outside of the building, personnel should proceed immediately to the guard gate and hand their badge insert to the guard (for mustering purposes). The film badge holder should be retained by its owner. Personnel are to assemble for muster at Building 110 gate. It should be remembered that persons might be contaminated, so care should be taken not to wander over more area than is necessary until a Hazards Control Monitor has checked shoes and clothing. Re-entry to the building will be under the direction of Hazards Control.

8.5. SPECIFIC AREAS

8.5.1. East and West Vaults

Should a nuclear accident occur in these vaults, the operators will sound the general disaster alarm and proceed as follows:

1. See that assembly is scrammed.
2. Close the exhaust damper in the West Vault exhaust line.
3. Shut all doors to vault if possible. This applies only to incidents that might occur while personnel are in the vault. During normal operation, the doors are closed.
4. Leave the area as quickly as possible.
5. Call 333 from the guard gate and report the accident.

In the event of a radioactive spill:

1. Scram any assemblies.
2. Sound general alarm.
3. Leave main blowers on, but close exhaust dampers in the West Vault and the containment area.
4. Shut all doors, etc. (isolate the area).
5. Check hands and feet for gross contamination and wait in the vicinity of the hand and foot counter for the arrival of a Hazards Control Monitor.
6. When cleared by the Hazards Control Monitor, muster at the main gate of the building with the other personnel.

8.5.2. Containment Building

1. Seal building.
2. Sound alarm.
3. Leave the area as quickly as possible.
4. Call 333 from the guard gate and report the accident.

ACKNOWLEDGEMENTS

Many members of the Neutronics Division contributed to various parts of this document. In particular, accident yield calculations were made by Oscar Kolar, details of the Snoopy and Nimbus systems were compiled by Fred Kloverstrom and Robert Ralston and the shielding calculations and measurements were made by Robert Donaldson.

APPENDIX A

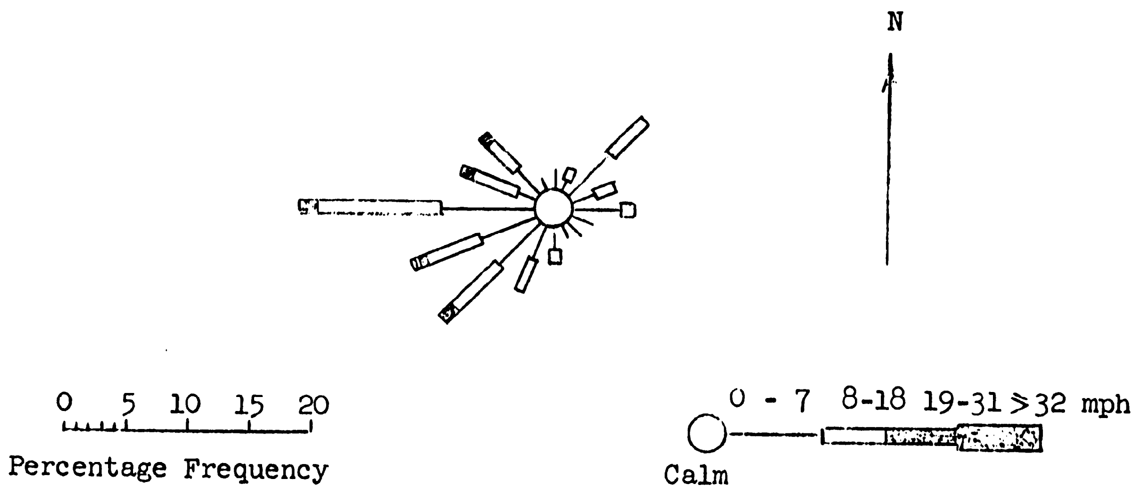
Climatological data for Livermore has been drawn mainly from three sources; the 80-year record of the U. S. Weather Bureau climatological station at Livermore, the ten-year (1934-1943) record of hourly weather observations made for the Weather Bureau by the Civil Aeronautics Administration (CAA) station at the Livermore Sky Ranch airport just west of town, and the short but important eighteen month record (February 1945-August 1946) from the Livermore Naval Air Station which is now the Site. In addition, and primarily to get upper air data, records for nearby Oakland and San Francisco have been consulted.

Average data on the surface wind direction and speed, temperature, humidity, rainfall, winds aloft, atmospheric stability conditions and other pertinent meteorological information are presented below.

Surface Wind Direction and Speed: Figures A-1 through A-4 are surface wind rose giving various annual and seasonal joint frequency distributions of wind direction and speed at Livermore. The percentage frequency of occurrences of a wind from any direction is represented by the total length of a compound bar extending from the center of the rose toward the direction. Percentage frequencies of certain ranges of wind speed are indicated by breaks in the bar, according to the code on each figure. The percentage frequency of calms is entered in the center of each rose.

Figure A-1 contains annual wind roses for both the Livermore CAA and the Navy stations. Each of these roses shows a primary direction maximum in the southwest quadrant and a secondary maximum in the northeast, although the most frequent directions at the CAA station are W and NE, whereas at the Navy station they are SW and N. The Navy station also has a higher frequency of calms. These roses show quite clearly the channelling effect of the valley location on the surface wind. It will also be observed that winds greater than 31 mph (miles per hour) are rare. Percentages of less than one-half of one per cent do not appear on the roses. In this connection, Table A-1

Annual CAA



Annual Navy

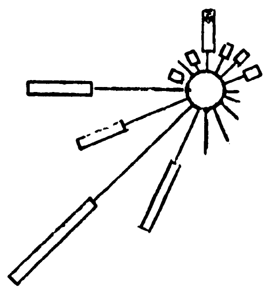


FIGURE A-1

ANNUAL WIND ROSES FOR LIVERMORE CAA AND NAVY STATIONS gives the fastest miles of wind ever recorded for each direction, at nearby Oakland, California. For strong winds such as these, the Oakland record should represent conditions at Livermore amply well. The fastest mile, recorded in February 1938, was 67 mph, a southwest wind.

TABLE A-1

Fastest Mile of Wind Recorded at Oakland, California

Month	Speed	Direction	Year
J	50	N	1948
F	67	SW	1938
M	45	SSE	1948*
A	41	SSE	1948
M	38	W	1949
J	44	W	1939
J	33	W	1939
A	34	W	1939
S	39	W	1939
O	43	W	1938*
N	45	W	1947
D	63	NE	1943

*Also on later dates

It is not possible to make any definite statement about the reality of the differences between the wind roses for the CAA and the Navy stations. However, it is reasonable to speculate that a longer period of record at the Navy station would more closely resemble the CAA station's record, since there is no evident reason to suspect any systematic difference. Accordingly, the remainder of the wind roses are based on the longer, more significant record of the CAA station.

Figure A-2 gives annual seasonal wind roses for the daytime hours, 0800 to 1830 LST (local standard time). The comparatively low expectancy of calms during the daytime is clearly shown. The

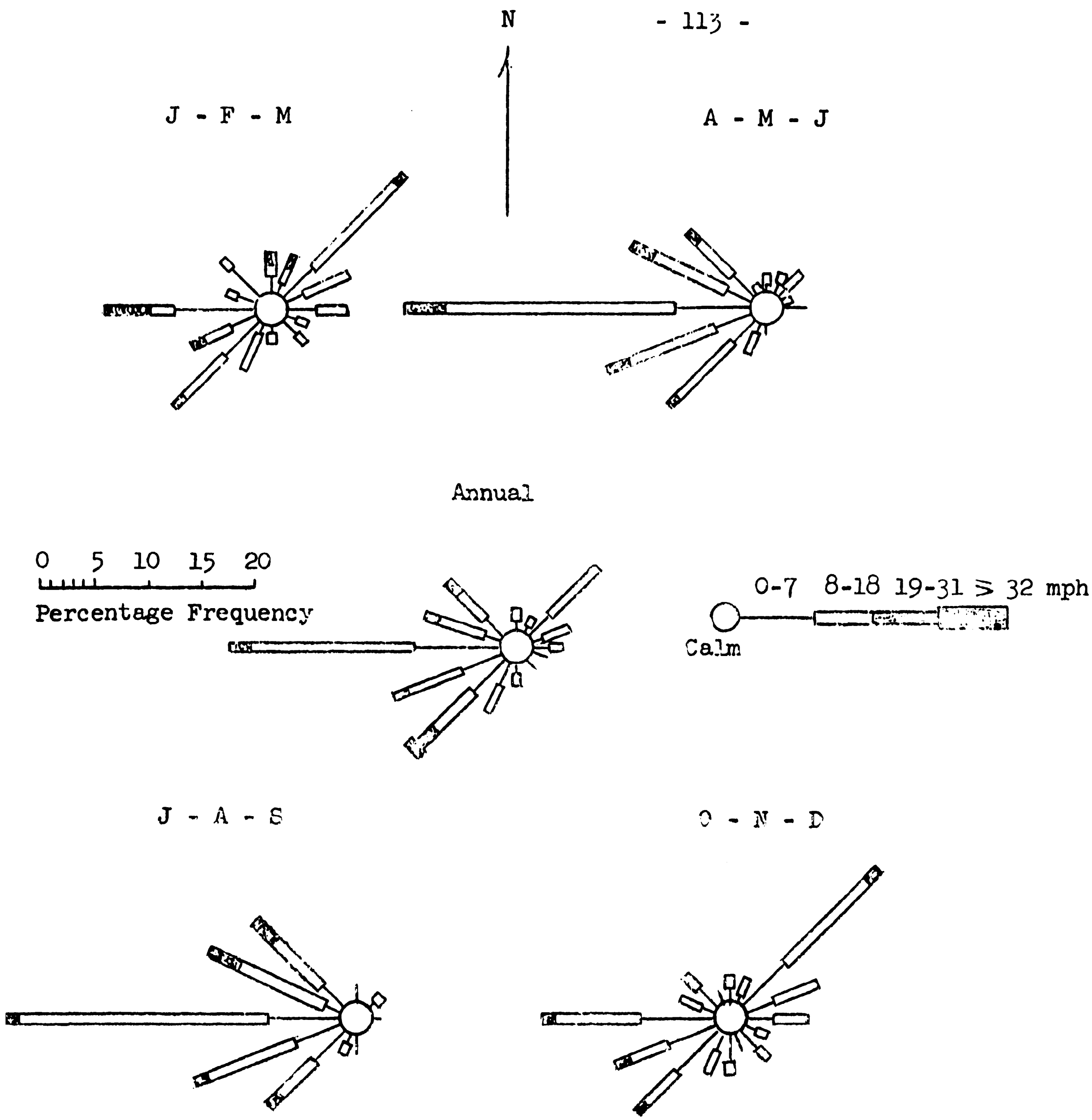


FIGURE A-2

ANNUAL AND SEASONAL WIND ROSES FOR DAYLIGHT HOURS

0800 - 1830 LST, AT LIVERMORE

annual rose locates the over-all wind speed maximum for Livermore; it is associated with a southwest wind direction (the most probable daytime direction). Notice also the pronounced west wind maximum during the summer half year (April through September) and the northeast wind maximum during the remainder of the year. The over-all double maximum of the annual roses is seen to be associated with two oppositely directed seasonal regimes. During the summer especially, the San Joaquin Valley, and to almost the same degree the Livermore Valley, are heated through the day and a large temperature contrast develops between the air in the valleys and the relatively cool maritime air of the Bay Region. The colder air then rushes into the San Joaquin Valley. The route followed by much of this air is across the San Pablo Bay and Suisun Bay areas, but some of it comes through the narrow, straight connecting valleys past the towns of Walnut Creek and Danville to the Livermore Valley. This air, probably with additional air which spills over the lower parts of the ridges between the Livermore Valley and the Bay area, crosses the Livermore Valley from west to east and flows over Altamont Pass. This phenomenon occurs almost daily, with considerable regularity, during the late spring and summer. During fall and winter, in contrast, the temperature gradient is directed in the opposite sense, and the flow from east to west through the Altamont Pass produces a northeast wind frequency maximum, although this is less pronounced than is the summertime effect.

The situation during the night is shown in Figure A-3. The main difference between these wind roses and the daytime ones is the higher frequency of calms and the lower frequency of winds about 18 mph. The locations of the direction maxima are much the same.

Figure A-4 has been prepared in order to give some information on the wind structure during periods of precipitation, to help assess the washout problem. On all these roses a definite shift of the direction frequency maxima into the southwest will be noticed. Otherwise, they are similar in structure to the other roses.

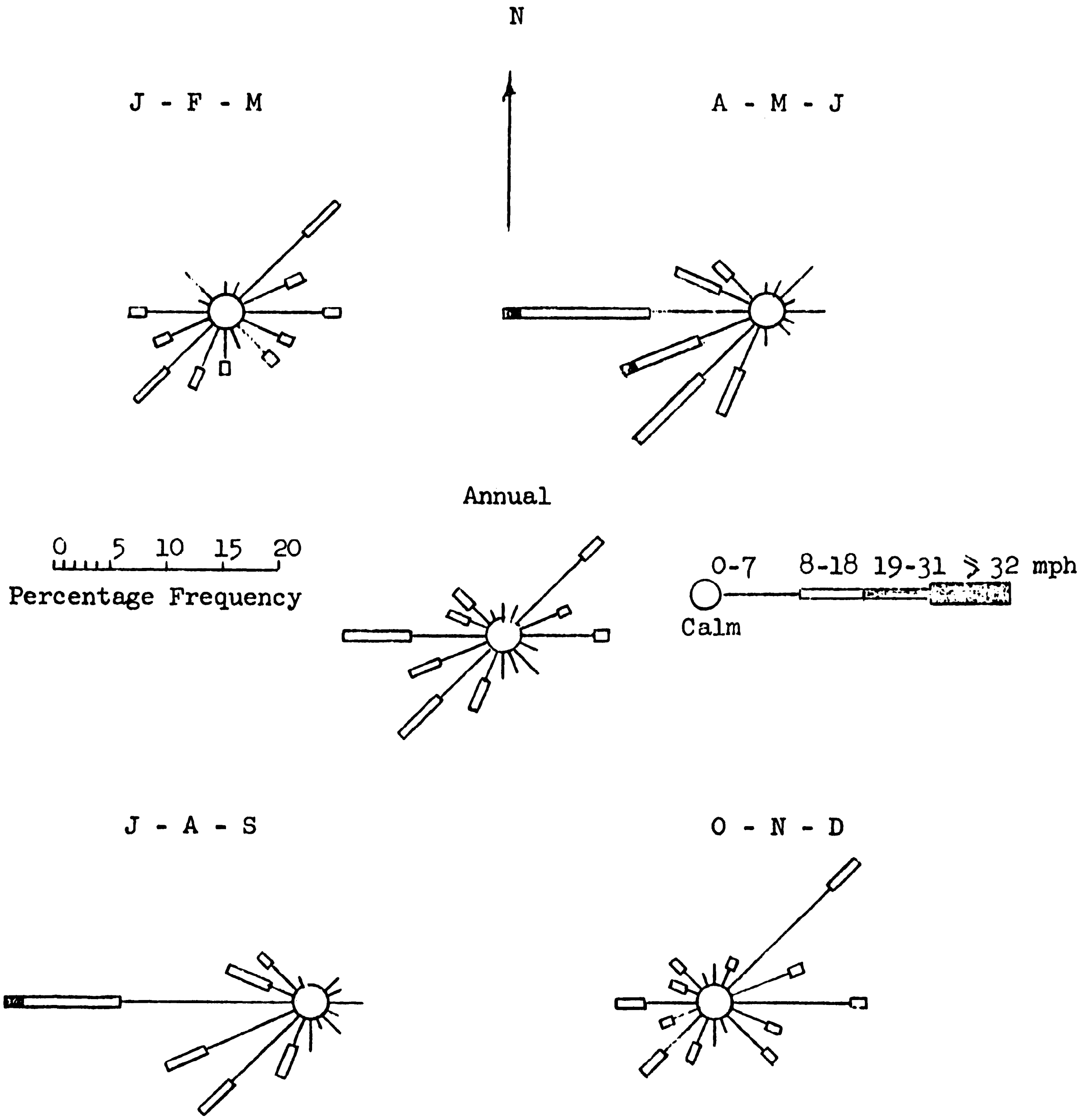


FIGURE A-3

ANNUAL AND SEASONAL WIND ROSES FOR NIGHT HOURS

1900 - 0730 LST, AT LIVERMORE

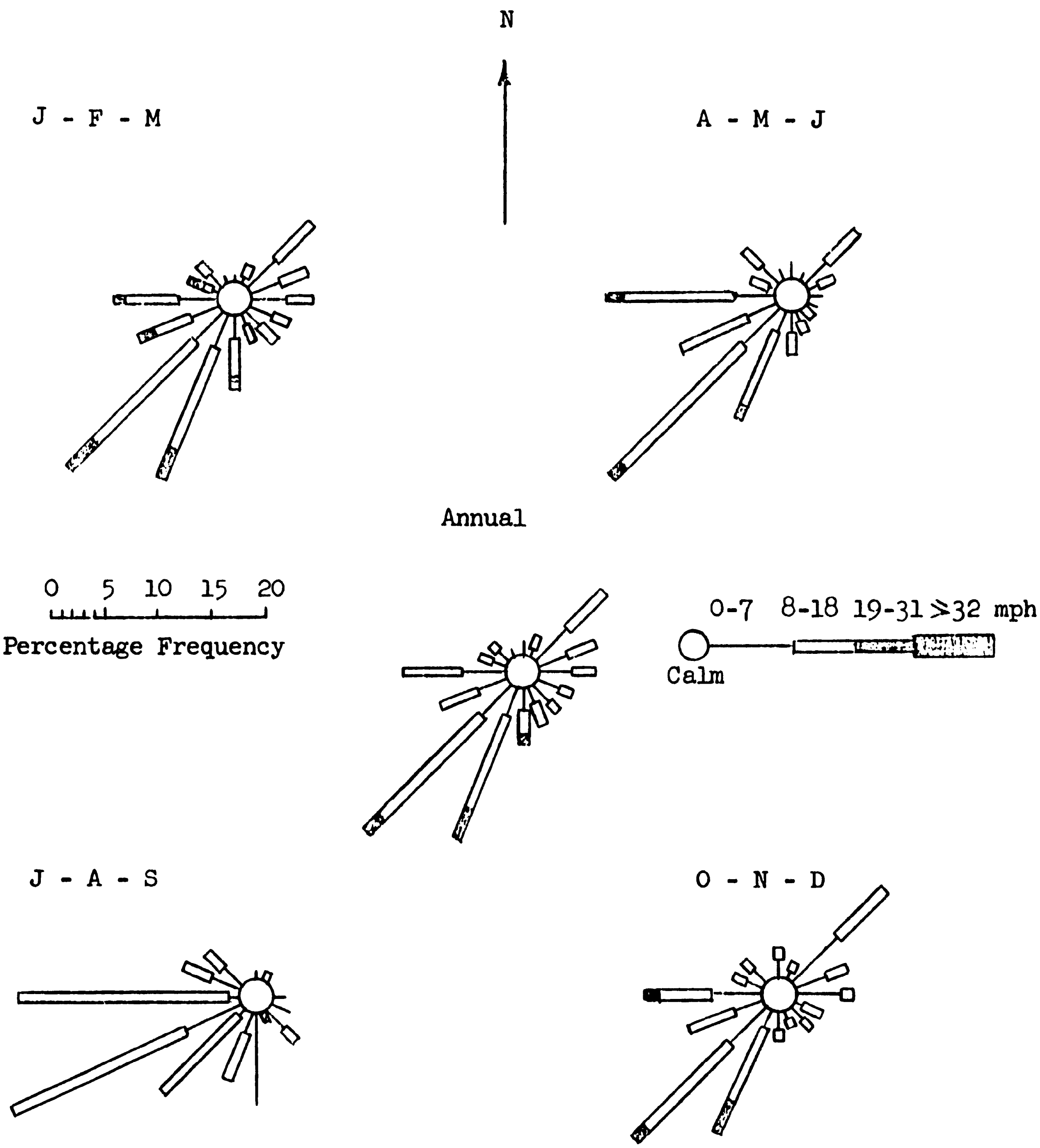


FIGURE A-4

ANNUAL AND SEASONAL WIND ROSES DURING PERIODS
OF PRECIPITATION AT LIVERMORE

Precipitation: The average annual precipitation at the Site should be about fifteen inches, varying between 7 and 25 inches for very dry and very wet years, respectively. Expected monthly and seasonal precipitation amounts at the Site are presented in Table A-2 and precipitation extremes in Table A-3. Most of the precipitation (virtually all of which is in the form of rainfall) occurs during the winter months in connection with Pacific storms, which occasionally bring enough rain to cause water to stand in some fields. Negligible amounts of solid precipitation (snow, sleet or hail) occur, the surface temperature as will be seen is below freezing only about one per cent of the time.

TABLE A-2

Expected Average Precipitation (inches)

Monthly

J	F	M	A	M	J
2.97 (3.49)	2.47 (3.34)	2.24 (2.52)	1.03 (1.27)	0.51 (0.57)	0.12 (0.17)
J	**A**	**S**	**O**	**N**	**D**
0.01 (0.01)	0.02 (0.03)	0.27 (0.08)	0.68 (0.87)	1.51 (1.50)	2.72* (3.34)

* Based on 80-year record

Figures in parentheses are rainfall amounts for Oakland, California

Winter	Spring	Summer	Fall
8.16	3.78	0.15	2.46

Annual

14.55

Average Snowfall

J	F	M	A	M	J	J	A	S	O	N	D
0.1	T**	T	0	0	0	0	0	0	0	0	0.1***

** T Trace

*** Based on 52-year record

No data on the occurence of thunderstorms at the Site are available, but at Oakland, which Table A-2 shows to have a similar rainfall regime, thunderstorms are rare, occurring on the average only one day a year, in January.

TABLE A-3

Precipitation Extremes (inches)

	Max. Mo.	Min. Mo.	Max. 24 hrs.
J	12.60	0.22	3.03
F	6.23	0.08	1.63
M	8.85	0.15	2.00
A	6.51	0.00	1.10
M	2.66	0.00	0.90
J	1.73	0.00	0.41
J	0.27	0.00	0.20
A	0.73	0.00	0.25
S	5.72	0.00	3.97
O	2.52	0.00	0.93
N	7.23	0.00	3.05
D	11.69*	0.17*	2.60**

*Based on 60-year record

**Based on 53-year record

The frequency of days with 0.01 inches or more precipitation, and of days on which heavy fog occurred, is shown in Table A-4. The rather uniform monthly distribution of fog days stands in contrast to the seasonal variation of precipitation, and it may be inferred that the wintertime fogs are associated with the general seasonal storminess but that the summertime fogs are radiational or else are associated with the occasional influxes of coastal stratus clouds. The small amounts of summertime precipitation can consequently be attributed partly to traces accompanying the stratus, and partly to occasional summertime showers, these being of no special severity.

TABLE A-4

Average Frequency of Certain Meteorological Phenomena

Average Number of Days

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
PPN 0.01"	11	10	9	5	3	1	t	t	1	3	6	10	59
Heavy fog*	4	2	1	2	2	2	2	3	2	2	2	3	27

t = less than 1/2 day

* visibility 1/4 mile

Surface Dry Bulb Temperatures: The expected annual average temperature at Livermore is 59°F. The expected average monthly temperatures, together with average maxima, minima and extremes are presented in Table A-5. At the site, the most frequent temperature will lie in the range from 40° to 70°F, and in fact this range should include about 75 per cent of all observed temperatures. Table A-4 contains the percentage frequency of occurrence of temperatures in various ranges. It is based on the ten-year record of the CAA station, and annual frequencies for the Navy station are included for comparison. Evidently, the temperatures at the two stations are directly comparable.

TABLE A-5

Expected Temperatures (°F)

	J	F	M	A	M	J	J	A	S	O	N	D
Average	48	51	54	57	61	66	71	72	68	63	55	49*
Av. Max.	57	61	65	71	76	82	88	87	85	77	67	58**
Av. Min.	37	39	41	44	47	51	54	53	52	47	41	37**
Highest	77	80	88	95	108	111	113	112	115	100	93	79***
Lowest	19	23	27	30	32	38	41	40	35	29	25	20***

* Based on 79-year record

** Based on 44-year record

*** Based on 54-year record

TABLE A-6

Expected Average Per Cent Frequency of Indicated Temperature Range

Temperature Range (°F)	Annual	J-F-M	A-M-J	J-A-S	O-N-D
90	2 (2)		2	6	*
80-89	5 (5)		5	12	2
70-79	9 (9)	1	13	19	5
60-69	18 (19)	8	24	25	16
50-59	36 (38)	37	40	35	35
40-49	22 (22)	38	15	3	29
30-39	7 (4)	15	1		12
30	1 *	1			1

* 0.5%

Based on ten-year record; figures in parantheses show comparison with Livermore Navy Station.

The temperature climate is essentially moderate. Table A-7 gives the percentage of the time that the temperature will be above or below a specified temperature. It shows, for example, that during January, February, and March, temperatures below 32°F should be expected about 2 per cent of the time. Temperatures above 90° and 100°F are similarly rare although sometimes in winter it is necessary to burn orchard heaters in the valley, and summer afternoons are likely to be uncomfortably hot. It was, for example, never cooler than 32°F between 1200 and 1800 LST during the winter months, and seldom warmer than 70°F between 2200 and 0900 LST during the summer, over the ten-year period of the CAA station's record.

TABLE A-7

Expected Percentage Frequency of Hours that Temperatures Will be Above or Below a Specified Temperature

Temperature (°F)	Annual	J-F-M	A-M-J	J-A-S	O-N-D
100	** (**)	0	**	*	0
90	2 (2)	0	1	5	1
80	6 (7)	0	6	16	2
70	14 (15)	1	17	35	6
60	31 (32)	7	40	58	20
50	67 (69)	40	79	96	54
40	8 (4)	16	1	0	13
32	1 (**)	2	**	0	2
20	** (0)	**	0	0	0

Winds Aloft: Pilot ballon runs are made four times daily at Oakland, California, and approximately three years of these observation have been examined to obtain the frequency of winds aloft at the 500 and 750 meter levels. Table A-8 shows the seasonal variation of wind direction frequency at 750 m. The most striking difference between the winds at this level and those at the surface is the fact that the maximum directions frequency is in the west-northwest and northwest rather than the west.

TABLE A-8

Percentage Frequency Wind Direction, 750 Meters MSL
by Seasons at Oakland, California

	Winter	Spring	Summer	Fall
N	9.9	7.8	3.2	7.7
NNE	13.2	7.0	2.5	10.6
NE	9.2	3.9	1.7	8.3
ENE	4.5	1.7	0.7	4.6
E	4.4	1.4	0.5	3.9
ESE	4.2	1.2	0.2	2.5
SE	4.5	1.1	0.5	2.6
SSE	5.0	2.0	0.6	2.4
S	5.4	3.4	2.4	3.9
SSW	5.0	4.1	5.6	4.6
SW	3.7	5.8	7.8	5.0
WSW	4.0	7.2	10.9	5.2
W	4.5	10.9	17.4	6.7
WNW	5.7	14.9	21.3	8.7
NW	6.7	14.5	14.2	9.5
NNW	6.4	8.6	5.3	7.0
Calm	3.7	4.5	5.2	6.8

Table A-9 giving the percentage frequency of various wind speed classes at 500 and 750 m. shows that there is not any great change with height from conditions at the surface up to 750 m.

TABLE A-9

Percentage Frequency of 500 and 750 Meter MSL Winds
by Speed Classes and Seasons

500 m, MSL

Speed* Season	0.1	2-7	8-14	15-21	21
W	5.2	71.4	21.8	1.4	0.2
S	15.3	65.9	18.6	0.2	---
S	5.6	84.9	9.3	0.2	---
F	8.1	78.3	12.6	1.0	0.1

750 m, MSL

Speed* Season	0-1	2-7	8-14	15-21	21
W	3.7	62.8	29.6	3.7	0.2
S	4.5	69.4	24.6	1.3	0.2
S	5.2	79.9	14.8	0.3	---
F	6.8	73.5	18.2	1.4	0.1

* Miles per hour

Atmospheric Stability: No radiosonde records are available for the Livermore area, but there would seem to be no obstacle in the way of making fairly accurate, generalized estimates of the low level atmospheric stability there, based on accepted meteorological principles. As a guide in this matter, Table A-10 showing the percentage frequency of occurrence of cloudiness (sky cover greater than five-tenths) in various ceiling ranges, annually and by seasons, has been prepared.

TABLE A-10

Percentage Frequency of Occurrence of Various Ceiling Ranges

Ceiling Range (hnds. ft.)										
0-4	1	2	3	4	1	1	1	1	2	3
5-9	2	3	2	2	1	3	1	5	2	2
10-14	2	4	3	3	2	6	2	6	2	3
15-19	2	3	3	3	2	4	1	3	2	2
20-29	5	5	8	7	5	5	1	2	4	4
30-49	7	5	15	11	7	4	1	*	6	5
50-99	4	3	7	6	2	2	1	1	4	3
100	77	75	59	64	80	75	92	82	78	78

* 15%

Day = 0800 - 1830 LST

Night = 1900 - 0730 LST

For the purpose of estimating the frequency of inversions below 1500 feet, the ceiling frequencies should provide an indication, not of the actual frequency of inversions, since this is certain to be greater than the frequency of low cloud occurrence, but of the location of the maximum inversion frequency. It is apparent, from Table A-10, that low level inversions are most frequent during the night and during the summer half year. Low cloud layers, in fact, occur a little more than 10 per cent of the time during the summer nighttime hours. During the day they occur only 4 per cent of the time. During the remainder of the year, on the other hand, ceilings below 1500 feet are about equally probable. The summer maximum of low cloudiness is associated with the well-known nocturnal stratus regime of the area.

The diurnal march of stability conditions in the low layers is expected to be normal at Livermore. In general, unstable conditions will predominate during the day, and isothermal and inversion conditions at night. Because of the somewhat high frequency of low stratus during the summer nights, more frequent isothermal, or even unstable conditions beneath the cloud base can be anticipated than would be found if the nights were all clear.

APPENDIX B

General Geology of Livermore Valley

This region lies in what has been termed the Southern Coast Ranges and is underlain by a basement of Franciscan rocks belonging to the Northern Franciscan Area. This series, even when overlain by a thin cover of sedimentary rocks, yields readily to deforming forces. Consequently extreme complexity of structure is almost always characteristic of regions where the Franciscan is present.

The general trend of the Coast Ranges is N. 27°W., but individual structural trends are commonly slightly oblique to that direction.

The post-Cretaceous sediments of the Coast Ranges are remarkable for variation in facies.

The Livermore region offers no exception to the foregoing general statements. The area has been subjected repeatedly to diastrophic forces since Franciscan time, and consequently the older rocks which are now exposed in the highlands have been compressed into a complex series of folds and faults which trend northwesterly across the area.

The structural features in the region control, to a large degree, the present topography and, to a smaller degree, the climate. The highlands are composed of uplifted masses of Jurassic, Cretaceous, and Tertiary rocks. The lowlands, such as the Livermore and Sunol Valleys, are commonly structural depressions filled with alluvium. The high northwest trending ridges and parallel valleys in the mountains commonly follow the strike of the alternating hard and soft strata or have an anticlinal or synclinal structure. All streams in the catchment area flow toward the structural and topographic depression occupied by the Livermore Valley.

Rapid lithologic changes occur in the Tertiary beds, and correlations of strata are made with difficulty except by faunal evidence.

Stratigraphy

Rocks of several ages from Franciscan to most recent alluvium are exposed at the surface in the catchment area. As will be pointed out, some of these rocks are of much greater interest than others in a study of ground water in the Livermore Valley.

Jurassic

Franciscan Formation: The Franciscan formation attains a thickness of 16,000 feet in the area. It consists predominately of arkosic sandstones, arenaceous shales and cherts. A few thin conglomeritic lenses occur. The Sedimentary rocks were intruded locally by diabase peridotite. Glaucophane-lawsonite-schists are found in places.

The regularity of bedding, the uniformity of grain, the small angle of cross-bedding, the marine cherts, and the foraminifera found in the Calera limestone member near San Francisco suggest that the greater part of the formation is of marine origin. Vickery suggested the Franciscan sediments were derived from a granitic land mass toward the west.

Rocks of Franciscan age are of special interest in this study because this formation is exposed throughout the large mountainous region in the southeastern portion of the catchment area and has furnished the largest part of the detrital material that forms the valley fill. As a consequence of the sandy and cherty nature of much of the fromation, the detrital material in the valley contains large quantitites of gravel and sand. These gravels and sands now form the aquifers which contain the ground water beneath the valley.

Cretaceous

Rocks of Cretaceous age in the area are of interest chiefly because they form Sunol Ridge west of the valley. Many of the Cretaceous beds are impervious. Consequently the ridge prevents the escape of ground water from valley toward the west. Only small exposures of Cretaceous rocks are found in other parts of the catchment area at the present time, but doubtless Cretaceous beds furnished a good deal of detrital material to the valley in the past. Vickery believed that the Cretaceous rocks were derived from a land mass toward the west.

Knoxville Formation: The Knoxville formation consists of 3,560 feet of marine sandstone, arenaceous and calcareous shale, and conglomerate. The lower part is now knownto be of Jurassic age, but the division between the Jurassic and Cretaceous has not been determined for the rocks in the Livermore region as far as the writer is aware.

Horsetown Formation: This consists of 680 feet of greenish sandstone and shale with lenses of conglomerate.

Chico Formation: A conglomerate 800 feet thick forms the base of the series in the Livermore region. Above the conglomerate a thick series of shale, sandstone, and conglomerate occurs. The thickness of the entire formation is 6,250 feet.

Tertiary

Beds of Tertiary age are exposed on the hills to the north, south, and east of the valley. The exposures on the east cover only a small area within the catchment area and hence are of slight interest to the present study. The exposures on the hills to the north and south, however, are formed by previous beds of Pliocene age and are of great interest because of the part they play in the accumulation and occurence of water in the valley. Tertiary beds have, of course, furnished a good deal of detrital material to the valley.

Eocene

Meganos Formation: The Meganos formation consists of 1,060 feet of angular, biotitic, quartzose sandstone with some conglomerate.

Tejon Formation: 1200 feet of fine gray sandstone with some beds of lignite make up this formation.

Oligocene

Rocks of Oligocene age are absent as far as known.

Miocene

Temblor Formation - Monterey Group: A basal conglomerate occurs at the bottom. This overlain by a thin sandstone of variable thickness. Above this occurs a thick body of thinly bedded opalized (diatomaceous) shale. The thickness of the entire group is about 2,250 feet.

Brones Sandstone: Shell breccia "reefs" and interbedded gray arkosic sandstones which have a total thickness of 1,060 feet.

Cierbo Group: The Cierbo group is made up of 700 feet of gray angular sandstone with a basal conglomerate.

Santa Margarita Formation: This formation consists of 750 feet of thickly bedded conglomerate. It contains also a characteristic sky-blue sandstone.

Pliocene

Orinda Formation: The Orinda formation is composed of slightly cemented sandstone and conglomerate and a small amount of shale. It was deposited as valley fill between Mission and Diablo ridges and attains a thickness of 1,500 feet. This formation is exposed on the hills north of the Livermore Valley and is of interest because it contains many pervious south-dipping beds. Rain enters these beds at the surface and percolates through aquifers in this formation toward the valley.

Livermore Gravels: This formation which is exposed on the hills south of the valley consists of 2,000 to 4,000 feet of fresh-water sandstones and conglomerates that dip northward toward the valley. The Livermore gravels are of special interest in the present study because of the previous character of most of the formation. Rain falling on these exposures percolates underground and travels down the dip of the aquifers toward the valley.

Quaternary and Recent

Bends of Pleistocene age have not been recognized by faunal evidence in the area but probably are present under the covering of more recent alluvium in the valley, since the trough existed prior to Pleistocene time. The upper portion of the Livermore gravels was probably deposited during the Pleistocene epoch.

Recent alluvium covers the floor of the valley except for small exposures of the Livermore gravels one mile west and one-half mile south of the town of Livermore. Quaternary alluvium fills the valley below the cover of recent alluvium. The alluvium lenses out against the foothills on all sides of the valley and reaches an undetermined thickness in the western portion of the area. Near Livermore the alluvium attains a thickness of at least 400 feet; near Pleasanton it attains a thickness of at least 500 feet.

The alluvium consists of boulders, gravels, coarse to fine-grained sands interbedded with yellow, brown, and blue clays. Most of the gravels and sands are only slightly compacted. Blue clay is rather rare except for a stratum immediately below the surface in the southwestern portion of the valley and a clay member that underlies the known aquifers.

The alluvium is an excellent aquifer and furnishes nearly all the ground water that is withdrawn from the valley. The great irregularity in yield of nearby wells and the difficulty of correlating the logs of wells only short distances apart is proof of the rapid changes that occur in the lithologic characteristics of the alluvium. However the small amount of cross-bedding and the lateral extent of some of the individual beds exposed in gravel pits between Pleasanton and Livermore suggest that some beds may have been deposited in quiet water.

A study of well logs gives some interesting information concerning the character of the alluvial material. Clay constituted 35.7 per cent and that gravel made up 21.4 per cent of the material penetrated by 50 wells drilled prior to 1911. The rest of the material was probably relatively impervious sandy clay. Most of the wells were less than 100 feet deep.

Since that time 15 to 20 wells have been drilled to a depth between 400 and 700 feet in the valley. Aquifers which yield sufficient water to be of economic value are penetrated to a depth of 400 feet near Livermore and 500 feet near Pleasanton.

Character of Material Penetrated by Wells to a depth of 400 feet near Livermore and 500 feet near Pleasanton

	East side Livermore		1/2 Mile W. Livermore		3-1/2 Mile W. Livermore		1-1/2 Mi. NE Pleasanton		1 Mi. W. Pleasanton	
	Feet	%	Feet	%	Feet	%	Feet	%	Feet	%
Gravel	113	28	114	40	130	34	222	43	190	37
Sand									40	8
Clay	291	72	282	70	250	66	292	57	282	55

It will be noted that both the amount and the percentage of gravel and sand increase persistently toward the west and reach a meximum in the area west of Pleasanton. Small gravel and coarse sand are often reported during the drilling of wells in that area. These facts indicate that the water-bearing material is finer grained and better sorted in the region west of Pleasanton than in the eastern part of the area nearer the apices of the cones.

The alluvium is most pervious along the courses of Arroyo Valle and Arroyo Mocho through the central and southern parts of the valley and is finer grained and less pervious in the eastern, northern, and northwestern portions of the valley.

An interesting blue clay member at least 200 feet thick has been penetrated by most wells that have drilled below the main aquifers. A few gravelly streaks occur in the clay but generally are not considered worth developing. The blue color of these beds is in marked contrast to the yellow and brown clays in the overlying 400 to 500 feet. Neither the age nor the origin of this member has been determined, but the character and thickness of the clays suggest that they may have been deposited in a lake.

Structure

Intricately folded and faulted Franciscan rocks are exposed over a large area in the southern part of the region. Tertiary beds covering the hills to the north, south, and east of the valley are more gently folded and faulted and have been warped into a broad, east-west trending syncline. The Livermore Valley lies in the trough of this syncline which involves beds at least as young as Pliocene.

The Livermore gravels which are exposed on the hills southeast of Pleasanton dip northward beneath the alluvium of the valley at an angle of 20° to 23°. The Orinda formation, which covers the hills north of the valley, dips southward at an angle of 40° to 45°. Both formations contain pervious beds through which water percolates toward the valley. The contact of these formations is concealed beneath the alluvium and hence has not been observed. An unconformity or a fault may be present at the contact though the formations are known to be, in part at least, of the same age.

The western end of the valley is bounded by the impervious Cretaceous rocks forming Sunol Ridge. These Cretaceous beds are separated from the much younger Pliocene rocks to the east by the Sunol Fault which trends

N. 27°W. across the western end of the valley. Branner (2) states that the region east of the Sunol Fault has been let down about 2,000 feet relative to the region west of the fault.

The Riggs Canyon Fault trends N. 37°W. through the Tertiary beds in the eastern foothills and may have had some influence in delineating the eastern end of the valley.

The structure of the flat-lying alluvium in the valley is typical of that commonly found in alluvial fans in the semi-arid western part of the United States. The alluvium has been deposited by intermittent streams whose courses across the valley have been changes repeatedly. Consequently rapid lithologic changes occur in many of the beds.

Data secured from detailed studies of the ground water show that the structure of the alluvium permits the division of the valley into four interconnected area.

The structural features of most interest in this study are, obviously, the structure of the alluvium in the valley, the synclinal character of the valley, and the presence of Sunol Fault along the west side of the valley.

Historical Geology

The geologic history of the region since the beginning of Franciscan time has been summarized as follows:

Franciscan (Probably Jurassic). Characterized by widespread marine and some continental deposition.

Post-Franciscan deposition. Characterized by folding, faulting, intrusion, metamorphism. Sunol Fault probably formed.

Shastan (Comanchian) to Lower Miocene (Inclusive). Characterized by slight diastrophism, broad areas of erosion, widespread deposition. The Livermore trough originated during this time.

Upper Miocene to Present (inclusive). Characterized by mountain-building, erosion, localized deposits. In the middle and, possibly, late part of the Pliocene period, faulting, close folding and even overturned folding occurred in the Livermore region. Following this erosion reduced the region to late maturity and, again, deformation occurred. Sediments were deposited in the Livermore depression. At present the mountains are being eroded and sediments are accumulating as alluvial cones and valley fill.

APPENDIX C

Operational Procedures for Snoopy Experiments

Responsibility

At least two members of the Critical Assembly Group will be present whenever Snoopy experiments are underway. One of these will be a senior physicist of the group who will be directly responsible for all phases of the operation. In addition, an electronics technician and a health chemist will be available.

It will be the responsibility of the physicist in charge to see that the pre-operation and operation logs are completed and kept current as the experiment proceeds.

Material Release and Records

The oralloy foils will be stored in foil boxes and these in turn will be kept in storage boxes mounted on the wall brackets. The storage boxes will be sealed with lead seals and their contents will be noted on an outside label, together with the initials of the person making the seal and the date of sealing. It is hoped this procedure will facilitate the monthly inventory of the foils. The amount of material required for the assembly in progress will be estimated and the necessary number of storage boxes will be opened and the foil boxes removed. No more storage boxes will be opened during the course of the assembly. If the number of boxes estimated as necessary is insufficient, a check will be made to see that the loading has been correctly done before additional material is made available. After the first assembly has been completed, it should be possible to make a fairly accurate estimate of the material required for a new assembly. This procedure is designed to prevent gross loading errors.

Batch numbers of the foils that are used will be recorded in the assembly log. As material is added to the core a record will be kept of the position of all foils in each layer. This can be conveniently done on the log sheets provided for this purpose. It is essential that this record be made as the material is added so chances for mistakes in loading are minimized. This record will also allow a particular assembly to be reproduced at a future time, using the same foils if necessary.

Instrumentation Checks

Preceding each day's operation, checks will be made to determine that each of the detectors is functioning properly, that the various trips operate the safety devices, and that each of the safety devices performs properly.

Counter checks will be made by positioning a Po Be neutron source in a standard geometry and observing the counting rate or signal. In this way, any change in the sensitivity of a particular counting chain can be detected.

There are two safety and one vault monitoring chain. Each of their elements will be checked to insure that the respective chain is broken when its scram point is reached or interlock violated.

The first safety chain includes all the detector and interlock scrams. Breaking this chain drops two safety rods (Nos. 1 and 3) and runs in the control rod. The second safety chain contains all of the detector scrams featured in the first chain. This second chain controls the third safety rod (No. 2), but because of the shared elements, both safety chains are scrammed when No. 2 scrams and all safety rods plus the control rod become inserted in the core. Safety Chain No. 2 provides a protective monitor while the vault is occupied for core alteration or stacking, and will scram Safety Rod No. 2 should a dangerous situation be approached.

The vault is considered safe for restricted occupancy whenever all of the following items in the monitor chain are accomplished:

1. Safety Chain No. 1 is scrammed.
2. Safety Rod No. 2 is fully raised.
3. Source No. 1 ($\sim 10^7$ n/sec) is extracted to a position above the ceiling timbers.
4. Source No. 2 ($\sim 10^5$ n/sec) is in place in the core.
5. The paraffin slab is fully retracted.

A solenoid lock on the maze door is wired to prevent entrance to the vault unless this monitor chain is made up and a vault alarm is sounded whenever the chain is broken.

The safety rods register full in or full out by tripping micro-switches of both limits of travel. The switches are operated by the rods themselves and not by the magnets that lift the rods. There is an additional switch which indicates that the rod has been picked up by the magnet, since it is not possible to see the rods themselves. The release time of the magnets and the drop time of the rods can be measured by timing the switch actuation after the scram signal has been initiated. Occasional checks will be made to verify that these times are being reproduced. There is no reason to expect any variation to develop through operation of the rods.

For Snoopy, the order of safety rod removal is important in that a rod induced accident could occur if reactivity is increased too rapidly by rod removal near criticality. Safety Rod No. 3 is electrically operated and designed to withdraw at a rate which will not allow such an incident to become dangerous if it should occur. A sequencing arrangement assures that Safety Rod No. 3 will be the last safety rod withdrawn because power for full extraction is not available to its motor drive unless the rods 1 and 2 are fully removed. Similarly, the control rod cannot be withdrawn unless all three safety rods are pulled. It is possible to lift both the control rod and Safety Rod No. 3 just off their respective bottom micro-switches with the rods 1 and 2 inserted, however, so that these elements can be tested. A daily check of sequencing and scramming by breaking safety chains will be made of all rods.

Interruption of either safety chain activates the control rod drive to run the rod into the core at maximum speed (10"/minute). In the event that the control rod is being withdrawn when the scram occurs, the drive motor is automatically reversed and the rod is driven in.

Measurements

Two general categories of experiments are contemplated: critical height measurements and zero power reactor flux investigations. Of course, initial experiments will be made to evaluate relative and actual worth of rods and paraffin slab.

1. Critical Height Measurements

a. General Procedure

Curves of inverse multiplication vs. core height for various rod configurations will be plotted from a series of counting rate measurements beginning with a core height definitely known to be sub-critical. Extrapolation of the various curves predicts critical height for the respective configurations and shows the amount by which the core height can be safely increased. In this way, the core will be built up in successively safe increments until criticality is reached.

b. Detailed Procedure (specific experiment)

Safety Rod No. 2 will be withdrawn from the core and Safety Chain No. 2 will automatically monitor the vault whenever the vault is occupied for Snoopy core adjustments. The assemblies will proceed in the following manner after the material has been obtained and the instrumentation checks previously outlined are performed. It is assumed that a particular core diameter and C/U ratio are specified, and the experiment is begun with a bare table.

(1) Base rates will be obtained with the appropriate Po Be neutron source nested in the core at its proper place 20" above the table top. A sterile core will be built up to the maximum height attainable in 6" high increments while taking appropriate counting rates for the following configurations:

(a) Safety Rods Nos. 1 and 3 plus control rod fully inserted

1. Paraffin slab against the wall.
2. Paraffin slab against the core.

(b) The sterile core will then be completely disassembled.

(c) Control rod fully inserted.

(d) All rods removed.

(2) The sterile core will then be completely disassembled.

(3) An initial stacking height of fertile material will be selected. As a conservative beginning the first increment is to be about half the calculated critical height for the configuration with all rods removed. (After reliable experimental data is obtained, the amount of the first loading step will be varied, but will never exceed that amount which gives a multiplication of five with all rods removed.)

(4) For the protection of personnel during the forthcoming stacking operation, the stacking monitor feature of Safety Chain No. 2 will now be prepared by setting all neutron level indicators to scram at levels equivalent to a multiplication of about 5 for the stacking configuration (all rods in except SR No. 2).

(5) The first increment of fertile core material will now be stacked. It is noted that a Snoopy design feature prevents vault entry unless Source No. 1 (10^7 n/sec) is withdrawn to a safe position above the overhead timbers and Source No. 2 (10^5 n/sec) occupies the core source well. As each layer of material is added to the core, a running account of the Oy foils associated with that layer will be kept on the core stacking form.

(6) The operators will leave the vault. The log N circuit will be set to scram at a power level of 1-1/2 watts and the pile period meters to scram at +15 sec. Both Beckman micromicroammeters will be set to scram at full scale and will be switched to appropriate new scales as the control elements are withdrawn. All other neutron level indicators will be set to scram at levels 50% above that anticipated from the inverse multiplication curves.

(7) Counting rates will now be taken for each of the base rate rod configurations. Both safety rods (Nos. 1 and 3) are to be followed carefully by the various count rate meters and the two Beckman micromicroammeters by switching scales only

as needed. Using the base rates obtained in Step (1), a multiplication can be defined for each rod configuration at each core height. Extrapolation of the inverse multiplication curves obtained in this way will predict the associated critical height.

(8) When counting rates for the current core height are completed, Safety Chain No. 1 will be scrammed preparatory to the next core height addition.

(9) From the points determined in Step (7) and the zero core height inverse multiplication of 1, the additional fertile material that can safety be added for the next step will be determined. Note that by inspecting the curve for the configuration of all rods (excepting SR No. 2) inserted and paraffin slab against the core, the operator can assure himself that the contamplated core height increase can be safely accomplished in spite of body tamping complications.

(10) Before entering the vault to build up the core, the stacking monitor feature of Safety Chain No. 2 will be prepared as specified in Step (3).

(11) Additional material will now be added to the core, and the foil loading for each layer recorded.

(12) Steps (6) thru (11) will be successively repeated until multiplications somewhat greater than 10 are reached. At this level the 1% worth of the control rod should begin to make a measurable change in the assembly multiplication. From this point on the procedure for each loading step will be as in Steps (6) thru (11) plus the following:

   (a) The counting rate will be taken with the control rod full in, half-way out, and full out.

   (b) An inverse multiplication will be calculated and plotted for each position.

   (c) Successive amounts of material, less than that required to make the assembly critical with the control rod full out, will be added. Extrapolation of the various inverse multiplication curves obtained in this way will allow an estimate of the various rod worths in terms of core height.

(13) Observing procedures in Steps (6) thru (11), material will now be added to bring the assembly to the point where it is just critical with all rods out. With the control rod half-way out, the source will be removed and the decay of the flux observed. The decay constant will be calculated and the inverse of this will be plotted versus the rod position.

(14) The source will be reinserted and the control rod pulled farther out. Again the source will be removed and a new decay constant calculated. From the plot of inverse decay constant versus rod position, a new control rod position can be selected. If positive periods cannot be obtained in this way, the assembly will be shut down and more material will be added. Note that the conjectured maximum worth of a 1/2" core layer when near critical is about 0.5%, and the control rod worth (which should be about 1%) was estimated in step (12). Since the assembly is never to be potentially capable of prompt criticality, at this point no more than a 1" layer will be added to the core at a time. If Step (12) predicts the control rod to be worth less than 0.8%, then a core increase of only 1/2" at a time will be made because the assembly is not to be critical with the control rod full in.

(15) With the new core mass, inverse time constant measurements will be made as a function of control rod position. Positive periods faster than 20 seconds will not be exceeded. Period scrams will always be set at 15 secs. Power level scrams will be set to trip at 1-1/2 watts.

c. Detailed Procedures (family of experiments)

Snoopy core diameters can be easily changed without disassembling an existing core. Consequently, it is experimentally more expeditious to study a family of cores at a time -- i.e., cores with the same C/U and reflector thickness but differing diameters.

Since the critical height (for a given C/U and reflector thickness) increases with decreasing diameter, investigations of a given core family will <u>always</u> begin with the largest diameter of interest.

(1) Following the procedures outlined in the preceding section for a specific experiment, determine the critical height for the largest core diameter of the family to be studied.

(2) Set the vault monitor. Decrease the core diameter but do not change the core height.

(3) With this initial height, follow the previously given detailed procedures to determine the critical height for the new (smaller) core diameter.

(4) Repeat in the above manner until the whole core family has been studied.

2. <u>Irradiation</u>

a. <u>General Procedure</u>

After the core has been loaded, scrams set and circuitry tested, the reactor will be brought up on a conservative period to a power level of about 1 watt. The irradiation will be carefully monitored, and after shut down a preliminary radiation survey will precede removal of irradiated samples from the core.

b. <u>Detailed Procedure</u>

It is assumed that the core to be studied has had an accurate critical height determination, that the core height is potentially only slightly more than delayed critical but definitely sub-prompt critical, and that the samples to be irradiated are properly placed in the core channels.

(1) Set the pile period meters to scram at + 15 sec., the pile power at 1-1/2 watts, and both Beckman micro-microammeters at full scale.

(2) Perform a thorough preoperational check of the circuitry as specified for critical height experiments.

(3) Place source No. 1 ($\sim 10^7$ n/sec) along with source No. 2 ($\sim 10^5$ n/sec) in the core.

(4) Withdraw SR No. 1 while following carefully with the Beckman micromicroammeters and switching scales only as needed.

(5) Remove Source No. 1 but leave Source No. 2 in the core.

(6) Withdraw SR No. 3 while carefully observing the Beckman micromicroammeters and switching scales when necessary.

(7) Carefully withdraw the control rod and bring the reactor up on about a 30 second period to a power level of approximately 1 watt.

(8) Level off at 1 watt and adjust to hold. Constantly monitor the reactor and make log entires of meter readings every 15 minutes.

(9) Upon completion of the irradiation period, shut down the reactor by scramming Safety Chain No. 1.

(10) Set the vault protective monitor.

(11) Make an appropriate radiation survey of the vault and core to ascertain when the irradiated samples can be removed.

(12) Remove the foil holders from the core channels and deliver to the counting room.

(13) The vault is otherwise to be out of bounds for general entry until the core has cooled to the satisfaction of the health chemist on station.